"B" Data Room

June 30, 1975

GEORGE C. MARSHALL SPACE FLIGHT CENTER

ATM DATA ANALYSIS STATUS REPORT

Space Sciences Laboratory

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA

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INTRODUCTION

This volume consists of a collection of progress reports by the various Apollo Telescope Mount PI groups giving the status of the ATM data analysis as of the end of FY-75 (June 30, 1975).

The analysis of this data by these groups and others is continuing under NASA sponsorship through the Space Sciences Laboratory of the Marshall Space Flight Center.

SKYLAB APOLLO TELESCOPE MOUNT

S052

WHITE LIGHT CORONAGRAPHY EXPERIMENT

High Altitude Observatory
National Center for Atmospheric Research
Boulder, Colorado

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I. INTRODUCTION

This report summarizes activities at the High Altitude Observatory, National Center for Atmospheric Research, under Contract NAS5-3950, by the White Light Coronagraph Experiment team (S-052). It includes a summary of progress and scientific results obtained since the completion of the Skylab mission employing data from the white light coronagraph observations on Skylab.

It is well known that the Apollo Telescope Mount program was an outstanding success in solar physics and that the results from all the ATM experiments, both singly and taken in total, will represent a significant impact on our current concepts and ideas of physical processes on the sun. In this brief report we summarize activities concerning the reduction of data from the coronagraph experiment and some major scientific results that have already been obtained or are in progress. Further, there is included a Bibliography of publications and presentations directly resulting from the efforts of the High Altitude Observatory experiment team.

II. DATA REDUCTION

Substantial efforts have been expended since the completion of the Skylab mission toward obtaining complete and accurate reduction procedures for the results obtained by the coronagraph experiment. These effects have basically culminated within the past month with the completion of a detailed manual for the National Space Science Data Center (NSSDC), Greenbelt, Maryland, concerning the use and reduction of experiment results. The manual and film copies of the original data will be forwarded to the NSSDC in August 1975.

As a brief summary of the reduction efforts, we note that the photometric calibration for both clear filter and polaroid filter information has been completed and both systematic and random errors in that calibration assessed. Further, the vignetting function of the coronagraph has been specified over the instrument field of view employing comparison photographs of the solar corona made by ground-based instruments during the eclipse of 30 June 1973 and lunar and stellar images obtained with the orbiting coronagraph throughout the Skylab mission. Next, the stray light in the coronagraph is currently being mapped over the entire instrument field of view through the use of observations of the contrast of lunar surface features during the eclipses of 30 June 1973 and 24-25 December 1973. Finally, extensive analysis of the polarization parameters of the instrument, including the polarization induced by the experiment itself, has been completed and procedures affected for the reduction of the polarization of the coronal light. Thus, in sum, with few minor exceptions, the procedures and detailed analyses necessary for the reduction of all coronagraph data have been completed and errors associated with this reduction established.

III. TRANSIENT CORONAL ACTIVITY

The major importance of transient coronal phenomena, unsuspected prior to the Skylab mission, has compelled the S-052 team to emphasize analysis of the events in an attempt to understand the origin, nature and effect of the events. A substantial fraction of the teams' scientific efforts have been directed toward those goals.

Coronal transients are often characterized by major local injections of mass and energy into the outer corona from lower in the solar atmosphere, but also, some apparently are rearrangements of material in the corona. The frequency of the mass ejection events during the Skylab mission was found to be considerably higher than anticipated before the mission: a total of 66 large mass ejections were detected during the 227 days of coronagraph operation and more than 40 additional events of a more subtle nature were also observed.

Examination of several of the large mass ejection transients in some detail (e.g., the events of 10 June, 10 August, 21 August, 26-27 August and 7 September) has resulted in the following estimates (even though there is a great deal of variability between events); typically the speed of the ejecta is approximately 500 km/sec, the mass ejected is in the range 10^{15} to 10^{16} grams and the kinetic energy is on the order of 10^{31} ergs. Clearly, these transient events represent major local perturbations to the corona and the flow of the solar wind.

The temporal and spatial distribution of more than one hundred transient events observed during the Skylab mission has been examined. When solar activity was not confined to one band of longitudes there was no particular clustering of the occurrence of coronal transients; however, during rotations late in the mission, the occurrence of coronal transients began to cluster more strongly in time. This temporal clustering, of course, implies a spatial clustering, and it was found that transients generally clustered about solar longitude 200 degrees. This increased clustering corresponded in time to the development of the active and quiet hemispheres discussed earlier; the spatial clustering of transients was coincident with the active longitudes.

The identification of transients with solar activity does not, however, necessarily imply a correlation with solar flares. It has been found that flares were <u>not</u> the prinicpal sources of transients during the Skylab mission. In one study, 66 transients described as large mass ejections were examined. Thirty of these transients were associated with solar surface phenomena; the remaining 36 large transients could not be so associated, but it is assumed that the majority of these 36 transients originated on the backside of the sun. Of the 30 transients with known associations, six were associated with flares, 19 with eruptive prominences, three apparently with infall-impact processes, and two with nearly simultaneous eruptive prominence and flare occurrences within the same active region. Significantly, if flares combined with eruptive prominences are neglected, eruptive prominences produced nearly three times as many coronal transients as did flares.

The size of a flare appears to be an important factor in determining whether or not the flare will cause a coronal transient. Because the coronagraph is most sensitive to coronal changes near the plane of the sky, flares within 45 degrees of the limb, with concurrent coronagraph observations, were examined for coronal transients. Taking the Hα importance as a measure of the flare activity, it was found that each (of 5) Importance 2 or 3 flare within 45 degrees of the limb produced a coronal transient; however, only 18 percent (3 or 17) of Importance 1 flares within 10 degrees of the solar limb produced transients, and no transients were caused by (29) Importance 1 flares occurring further than 20 degrees from the limb. The same strong correlation was found when the x-ray flux from the flaring region was used as a measure of the flare's importance. In addition to the association of energetic flares with transients, there was a strong correlation between coronal transients and Hα material ejected from a flare. In fact, every flare within 45 degrees of the limb which produced a coronal transient also had a Hα mass ejection.

In sum, flares produced only a small fraction of the mass ejections in the corona during the Skylab mission. While the more energetic flares had a higher probability of causing coronal transients, disturbances in the corona above 2 $R_\odot$ associated with flares seem to be directly correlated with the ejection of material from the flare site.

Are there signatures of these transient events in the interplanetary medium? The answer to this question is, and will prove to be, elusive since a) the coronagraph is biased toward events occurring near the solar limb, b) there are relatively few spacecraft transiting the interplanetary medium that are favorably situated for the detection of solar limb events, and c) those spacecraft do not regularly transmit data over extended periods. In the case of one coronal transient associated with a major flare on the sun on 7 September 1973, a strong shock wave was observed near 1 AU by the Pioneer 9 spacecraft 44 hours after the flare. For this event it was found that coronal energy and mass estimates based upon coronagraph observations were in close agreement with estimates based upon interplanetary spacecraft observations. However, this transient appears exceptionally energetic and massive as compared with other transient events during the mission and the solar wind disturbance at 1 AU was also unusually large. A search for interplanetary disturbances correlated with more typical coronal events has thus far proven unsuccessful; however, a clue to the type of disturbance which might be expected at 1 AU may be found in work concerning another coronal transient event - that of 14-15 September 1973. This event was one of few observed simultaneously with the metric radio wavelength spectroheliograph of the Commonwealth Scientific and Industrial Research Organization (CSIRO) and with the white light coronagraph. A metric radio burst associated with this event has been examined; under the assumptions that the radio emission was gyro-synchrotron radiation or plasma emission, the magnetic field strength during the transient event was determined. For the first time, then, the relative importances of magnetic, kinetic, and thermal energy densities in a transient event could be made. It was found that, in contrast to the normal solar wind expansion, the magnetic and kinetic energy densities in this transient event were roughly equivalent and greatly exceeded the thermal energy density. This result suggests that it may be fruitful, within the constraints imposed by the limited data coverage, to examine available interplanetary records for correlations between transient coronal activity and anomalously strong magnetic field perturbations and/or ordered field configurations. This work, utilizing IMP 6, 7 and Pioneer 10 results recently received, is just beginning.

Events of 21 August and 26-27 August are relevant to the study of the origin of the characteristic white light loops seen so frequently by the coronagraph, particularly when the events are examined with concomitant Hα and He II observations from the ground and Skylab. For example, a polarization analysis of the loop part of the event of 21 August indicates that the radiance is due entirely to electron scattering from material at the solar limb and that this material is hot and of coronal origin. A small bright area, which is cospatial with a He II λ304 eruptive prominence observed by the Naval Research Laboratory on Skylab, was also analyzed using polarization data. This area had a much lower level of polarization which is interpreted as being due to a 50 percent Hα emission from an area in the corona of high density (2×10^8 electrons/cm^3 at 1.8 $R_\odot$) and cool temperature (20,000 K > T > 5000 K). The time sequence of Hα, He II, and coronal white light show that: the prominence was first cool and began to erupt; as the eruption progressed, magnetic field lines above the prominence expanded into the corona carrying material with them giving rise to the loop transient in the outer corona; during later phases of the eruption the prominence began heating as evidenced by a reduction in Hα emission and an increase in He II emission. The prominence finally dissipated in replacing the coronal material carried out at the expanding loops.

IV. LONG-TERM VARIATIONS AND CORONAL STRUCTURES

One of the principal pre-mission motivations for the flight of the Skylab coronagraph was the detailed investigation of the nature of long-term variations, i.e., investigations of the nature of the evolution of the overall magnetic field of the sun. The regular synoptic observations of the coronagraph have permitted the identifications of several long-lived solar features - features whose appearance is similar over repeated limb passages. The identification of such long-lived stable structures is of importance, for if the shape of the coronal streamer is indicative of the streamers' magnetic field configuration, these streamers will be suitable to test the validity of outer coronal magnetic field computations, because the computations assume the photospheric roots of the field remain unchanged from one limb passage to the next. Preliminary examination of the results of both computation and observation do not yield compelling evidence for a stable computed magnetic structure which might be associated with observed streamers. Clearly, this area will be the subject of intensive future efforts.

A stable structure - observed during six limb passages from June - August 1973 is currently under investigation. The streamer, at latitude 20 degrees and an approximate longitude 210 degrees, has an apparent association with McMath region 379/424/475. Temporal variations in the structure, the measured intensity of the streamer during several limb passages, and the variation in this measured intensity are all currently under investigation.

Another important example of long-term variations in the corona currently under study is that concerned with the response of the outer solar corona to the dimunition of surface activity over a hemisphere of the sun. During the Skylab mission period, one hemisphere suffered a substantial dimunition in solar activity -- as measured by a) the Ca K intensity-area product; b) the mean Zürich sunspot number averaged over the hemisphere; and c) the total photospheric magnetic flux. Preliminary examination of the outer coronal configuration present above this hemisphere indicates that coronal features became restricted in latitude as activity decreased, and the appearance of the corona late in the mission over the quiet hemisphere became quite similar to past descriptions of the solar minimum corona (i.e., the dominant forms in the corona were extended equatorial streamers). This particular form of the corona is similar to that previously computed for a magnetohydrodynamic model of the coronal flow employing a dipolar magnetic field. It suggests therefore that the magnetic field over the quiet hemisphere approximates a weak dipolar field. The study of this particular example of the evolution of coronal forms will, we anticipate, shed light on the formation and nature of the outer coronal magnetic field which exists at the time of solar minimum activity.

V. LIBRATION CLOUDS

An attempt to determine the radiance of forward scattered sunlight from particles in lunar libration regions was made with the coronagraph on Skylab. It was found that the libration regions could not be distinguished against the solar K + F coronal background; thus an upper limit to the libration cloud radiance was found to be 2.5×10^{-11} $B_{\odot}$, where $B_{\odot}$ is the mean radiance of the solar disk. Then, employing a model of the particle composition and size distribution for material which has been proposed for the interplanetary medium, upper limits for the density enhancements in the libration region from the upper limit of the forward scattered radiance measured were determined. In a similar manner, the actual space density enhancement was calculated using earlier observations of backscattered radiance from the libration region. Enhancements of a factor of 10^2 - 10^3 were thus determined; the actual value, depending upon material composition and the size distribution employed in the calculation. From the combined forward and back scattered observations, it was possible to eliminate from consideration libration clouds whose power law particle size distribution exponent K is 2.5 and complex index of refraction M is 1.33-0.05i and 1.50-0.05i (i.e., absorbing ice and quartz particles, respectively). With the remaining candidate models for libration clouds it is possible to calculate the radiance contrast with respect to the K and F coronal background. It is found that this calculation leads to a maximum in the vicinity of solar elongation angle approximately 30 degrees.

The study resulted in a thorough assessment of systematic variations which may be present in the observed radiance in the background K + F coronal components, at least during several times during the mission. It was found that no systematic temporal variations were present to within 2.5 - 3.0 percent for the two times of libration cloud observations. This detection limit is on the order of a factor of ten smaller than the scattered light in the instrument and a factor of 40 less than the background F-coronal radiance. It is a conservative upper limit since the difference between the mean radiance derived from all photographs at the time of libration cloud passage and the mean radiance of all comparison pictures was less than one percent.

These studies were carried out in collaboration with A. Hopfield of the Princeton Day School, Princeton, New Jersey, one of the Skylab Student Science competition winners.

VI. SEARCH FOR INTRA-MERCURIAL OBJECTS

The search for intra-Mercurial objects was performed by visually scanning copies of the white light coronagraph film data. From the results of this search it is concluded that objects of sixth magnitude or brighter, orbiting inside the orbit of Mercury, did not pass through the white light coronagraph field of view during the search periods.

It is also inferred that previously unknown comets or asteroids, brighter than sixth magnitude, except Comet Kohoutek, were not present in the apparent vicinity of the sun during the times covered in this search. The images of such objects would have been observable, but were not found, during the scanning of the photographs. Although this search, like others, has produced a negative result, it adds to the information concerning objects orbiting within Mercury's orbit. Further investigations dealing with such objects are necessary to achieve a definitive conclusion on the problematical existence of intra-Mercurial objects.

These studies were carried out in collaboration with D. Bochsler of Silverton Union High School, Silverton, Oregon, one of the Skylab Student Science competition winners.

VII. COMET KOHOUTEK

As is well known, the coronagraph obtained over 1500 photographs of Comet Kohoutek during its period of minimum elongation passage to the sun and at times requiring off-pointing of the ATM cannister from the sun. These observations provide an opportunity to determine the radiance of the comet at a point in its evolution normally unobservable and permit examination of characteristics of the dust tail, again at normally unobservable periods of the comet's history. Examination of the coronagraph results towards these goals are being carried out in collaboration with U. Keller (Max-Planck, Münich). It is to be anticipated that photometry of the comet will be complete within the next several months and preliminary results concerning the orientation of both the dust tail and the well known sunward spike will be completed in the near future.

VIII. BIBLIOGRAPHY

Gosling, J. T., E. Hildner, R. M. MacQueen, R. H. Munro, A. I. Poland, and C. L. Ross, 1974: Mass Ejections From the Sun: A View From Skylab, J. Geophys. Res., 79, 4581.

Gosling, J. T., E. Hildner, R. M. MacQueen, R. H. Munto, A. I. Poland, and C. L. Ross, 1975: Direct Observations of a Flare Related Coronal and Solar Wind Disturbance, Solar Phys., 40, 439.

Gosling, J. T., 1975: Large-Scale Inhomogeneities in the Solar Wind of Solar Origin, Rev. Geophys. & Space Phys., 13.

Gosling, J. T., A. J. Hundhausen, and S. J. Bame: 1975: Solar Wind Stream Evolution at Large-Heliocentric Distances: Experimental Demonstration and the Test of a Model, J. Geophys. Res. (submitted).

Hildner, E., J. T. Gosling, R. M. MacQueen, R. H. Munro, A. I. Poland, and C. L. Ross, 1975: The Large Coronal Transient of 10 June 1973: I. Observational Description, Solar Phys. (in press).

Hundhausen, A. J. and J. T. Gosling, 1975: Solar Wind Structure at Large Heliocentric Distances: An Interpretation of Pioneer 10 Observations, J. Geophys. Res. (in press).

MacQueen, R. M., 1974: Skylab: A Progress Report, IAU - Coronal Disturbances, ed. Gordon Newkirk, Jr., 489.

MacQueen, R. M., J. T. Gosling, E. Hildner, R. H. Munro, A. I. Poland, and C. L. Ross, 1974: The High Altitude Observatory White Light Coronagraph Experiment, IAU - Coronal Disturbances, ed. Gordon Newkirk, Jr., 505.

MacQueen, R. M., J. A. Eddy, J. T. Gosling, E. Hildner, R. H. Munro, G. A. Newkirk, Jr., A. I. Poland, and C. L. Ross, 1974: The Outer Solar Corona as Observed From Skylab: Preliminary Results, Astrophys. J. Letters, 187, L85.

MacQueen, R. M., J. T. Gosling, E. Hildner, R. H. Munro, A. I. Poland, and C. L. Ross, 1974: The High Altitude Observatory White Light Coronagraph, Proceedings on Instrumentation in Astronomy, 44, 207.

MacQueen, R. M., J. T. Gosling, E. Hildner, R. H. Munro, A. I. Poland, and C. L. Ross, 1975: Initial Results From the High Altitude Observatory White Light Coronagraph on Skylab - A Progress Report, Proc. Royal Soc. of London (in press).

Munro, R. H., J. T. Gosling, E. Hildner, R. M. MacQueen, A. I. Poland, and C. L. Ross, 1974: Observations of Flare Associated Coronal Dynamics Above 2 $R_\odot$, Manuscripts presented at the Conference on Flare Related Magnetic Field Dynamics, Boulder, Colorado, 23-25 September 1974.

Munro, R. H., J. T. Gosling, E. Hildner, R. M. MacQueen, A. I. Poland, C. L. Ross and Alison Hopfield, 1975: A Search for Forward Scattering of Sunlight From Lunar Libration Clouds, Planet. Space Sci., (in press).

S052 PRESENTATIONS

"Skylab: A Progress Report", R. M. MacQueen, invited paper IAU Symposium No. 57, Surfers Paradise, Australia, 10 September 1973.

Colloquium, Colorado State University, A. I. Poland, Fort Collins, Colorado, October 1973.

"The Outer Solar Corona as Observed From Skylab", A. I. Poland, invited paper at American Astronomical Society, Tucson, Arizona, 2-6 December 1973.

"Preliminary Results: White Light Coronagraph", E. Hildner and R. H. Munro, invited paper at American Astronomical Society, Honolulu, Hawaii, 9 January 1974.

"Coronal Holes", Panel discussion of American Astronomical Society Members, R. H. Munro, Honolulu, Hawaii, 9 January 1974.

Colloquium, University of California, J. T. Gosling, Los Angeles, California, 5 February 1974.

"White Light Coronagraph: Instrument and Observations", R. H. Munro, invited talk at Rocky Mountain Division of Optical Society, Boulder, Colorado, 21 February 1974.

"The High Altitude Observatory White Light Coronagraph Experiment on Skylab", R. M. MacQueen, invited paper at Society of Photographic and Instrumentation Engineers, Tucson, Arizona, 5 March 1974.

Colloquium, Sacramento Peak Observatory, R. M. MacQueen, Sunspot, New Mexico, 6 March 1974.

"The Eruptive Prominence of August 21, 1973 Observed from Skylab in the White Light Corona and in the He II 304 Å Chromosphere", A. I. Poland, J. D. Bohlin, G. E. Bruckner, J. D. Purcell, V. E. Scherrer, N. R. Sheeley, and R. Tousey, invited paper of American Astronomical Society, Lincoln, Nebraska, 26-29 March 1974.

"Direct Observations of Magnetic Bottles", J. T. Gosling, invited paper at Asilomar Solar Wind Conference, Monterey, California, 26 March 1974.

"The Outer Corona as Observed From Skylab - An Overview", J. T. Gosling, invited paper at American Geophysical Union, Washington, D.C., 8 April 1974.

"The Transient of 10 June 1974: I. Observations", R. M. MacQueen, American Geophysical Union, Washington, D.C., 8 April 1974.

"The Coronal Transient of 10 June. II. Dynamics", E. Hildner, American Geophysical Union, Washington, D.C., 8 April 1974.

"Structure of a Polar Coronal Hole Above 2 $R_\odot$", R. H. Munro, American Geophysical Union, Washington, D.C., 8 April 1974.

Colloquium, Missouri Valley College, E. Hildner, Marshall, Missouri, 12 April 1974.

"The White Light Coronagraph Experiment on Skylab", R. M. MacQueen, invited paper, Optical Society of America, Washington, D.C., 22 April 1974.

Colloquium, Goddard Space Flight Center, R. M. MacQueen, Greenbelt, Maryland, 24 April 1974.

"Early Results from Skylab/ATM Coronagraph", E. Hildner, invited paper at Santa Fe Meeting, Santa Fe, New Mexico, 29 May 1974.

Colloquium, Fraunhofer Institute, A. I. Poland, Freiburg, Germany, 11 June 1974.

"The Response of the Corona to Solar Transient Phenomena", J. T. Gosling, Invited paper at Solar γ-, X-, and EUV Radiation Symposium, Buenos Aires, Argentina, 11 June 1974.

Colloquium, Observatoire de Geneve, A. I. Poland, Geneva, Switzerland, 13 June 1974.

Colloquium, Federal Institute of Technology, A. I. Poland, Zurich, Switzerland, 17 June 1974.

"An Interplanetary Disturbance Associated with Directly Observed Outward Material Motions in the Solar Corona at 6 $R_\odot$", J. T. Gosling, STP/COSPAR, São Paulo, Brazil, 18 June 1974.

"The ATM White Light Coronagraph", R. M. MacQueen, Invited paper at COSPAR, São Paulo, Brazil, 24 June 1974.

Colloquium, Observatoire de Paris, A. I. Poland, Paris, France, 24 June 1974.

Colloquium, Strassenburg Planetarium, J. T. Gosling, Rochester, New York, 18 August 1974.

"The Solar Corona as Seen From Skylab", E. Hildner, AIAA-American Geophysical Union Conference on Scientific Experiments of Skylab, 30 October - 1 November 1974.

Seminar, Astro-Geophysics Department, University of Colorado, E. Hildner, Boulder, Colorado, 25 November 1974.

"Solar Flares and Outer Coronal Disturbances", R. H. Munro, American Geophysical Union, San Francisco, 12-17 December 1974.

"The Frequency and Heliographic Location of Coronal Transients During the Skylab Mission", E. Hildner, American Geophysical Union, San Francisco, California, 12-17 December 1974.

"A Search for Forward Scattering of Sunlight From the Lunar Libration Clouds", C. L. Ross, American Geophysical Union, San Francisco, California, 12-17 December 1974.

"White Light and Radio Studies of the Coronal Transient of 14-15 September 1973. I: Observations and Emission Mechanisms", G. Dulk and J. T. Gosling, American Geophysical Union, San Francisco, California, 12-17 December 1974.

"White Light and Radio Studies of the Coronal Transient of 14-15 September 1973. II: The Dynamics of the Event", R. M. MacQueen and K. V. Sheridan, American Geophysical Union, San Francisco, 12-17 December 1974.

"Direct Observations of a Flare Related Coronal and Solar Wind Disturbance", J. T. Gosling, American Geophysical Union, San Francisco, California, 12-17 December 1974.

"The Outer Solar Corona at Solar Minimum Activity - Coronagraph Observations from the Apollo Telescope Mount of Skylab", R. M. MacQueen, paper presented at Royal Society Discussion Meeting on the Physics of the Solar Atmosphere, London, England, 14-15 January 1975

"The Effects of Flares Upon the Outer Solar Corona, R. H. Munro, American Astronomical Society/Solar Physics Division Meeting, Boulder, Colorado, 20-22 January 1975.

"White Light and Radio Studies of the Coronal Transient of 14-15 September 1973. I: Observations and Emission Mechanisms", R. Robinson and R. M. MacQueen, American Astronomical Society/Solar Physics Division Meeting, Boulder, Colorado, 20-22 January 1975.

"White Light and Radio Studies of the Coronal Transient of 14-15 September 1973. II: The Dynamics of the Event", J. T. Gosling and G.A. Dulk, American Astronomical Society/Solar Physics Division Meeting, Boulder, Colorado, 20-22 January 1975.

"Observations of a Long Lived Coronal Streamer", A. I. Poland, American Astronomical Society/Solar Physics Division Meeting, Boulder, Colorado, 20-22 January 1975.

Colloquium, Sandia Laboratory, A. I. Poland, Alburquerque, New Mexico, 30 January 1975.

Colloquium, Los Alamos Scientific Laboratories, A. I. Poland, Los Alamos, New Mexico, 30 January 1975.

Colloquium, University of Maryland, J. T. Gosling, College Park, Maryland, 19 February 1975.

Colloquium, The Pennsylvania State University, A. I. Poland, State College, Pa., 25 February 1975.

Colloquium, Los Alamos Scientific Laboratories, J. T. Gosling, Los Alamos, New Mexico, 27 February 1975.

Colloquium, National Oceanic & Atmospheric Administration, E. Hildner, Boulder, Colorado, 4 March 1975.

Colloquium, University of California-Berkeley, Space Science Laboratory, J. T. Gosling, 10 April 1975

Colloquium, Ohio State University, J. T. Gosling, Columbus, Ohio, 17 April 1975

Colloquium, University of Illinois, Urbana, Illinois, A. I. Poland, 22 April 1975.

Colloquium, Denver University, Denver, Colorado, J. T. Gosling, 23 April 1975.

Colloquium, University of Alabama in Huntsville, School of Science and Engineering, Huntsville, Alabama, E. Hildner, 25 April 1975.

Colloquium, Johnson Space Center, Houston, Texas , R. M. MacQueen, 1 May 1975.

Colloquium, Utah State University, Logan, Utah, E. Hildner, 7 May 1975.

Colloquium, University of Washington, Seattle, Washington, A. I. Poland, 21 May 1975.

Colloquium, University of Minnesota, Minneapolis, Minnesota, J. T. Gosling, 28 May 1975.

"A Review of Skylab/ATM Observations and Analyses of Coronal Transients", J. T. Gosling, invited paper at COSPAR Meeting, Varna, Bulgaria, 4 June 1975.

"The Character and Temperature of a Coronal Transient I: The Event of 26-27 August 1973", J. D. Bohlin, E. Hildner, R. T. Hansen, (presented by J. T. Gosling), COSPAR Meeting, Varna, Bulgaria, 4 June 1975.

"The Character and Temperature of a Coronal Transient, II: 21 August 1973, R. H. Munro and A. I. Poland, COSPAR Meeting, Varna, Bulgaria, 4 June 1975.

"A Temporal Study of the Radiance of the F-corona Close to the Sun", R. H. Munro, presented at IAU Colloquium #31, Heidelberg, Germany, 10 June 1975.

"A Search for Forward Scattering of Sunlight From the Lunar Libration Clouds, C. L. Ross, presented at IAU Colloquium #31, Heidelberg, Germany, 10 June 1975.

"Summary of the Solar Corona/Zodiacal Light From Apollo 15, 16, and 17", C. L. Ross, presented at IAU Colloquium #31, Heidelberg, Germany, 10 June 1975.

SKYLAB APOLLO TELESCOPE MOUNT

S054

X-RAY SPECTROGRAPHIC TELESCOPE

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1.0 INTRODUCTION

This document is a Summary Report for the data analysis phase of the AS&E S-054 experiment from the recovery of the data from the first manned mission through 30 June, 1975. It is divided into two sections; the first describes the procedures and facilities which have been developed during the program for the analysis of the flight data while the second summarizes the major results which have been obtained so far.

2.0 DATA REDUCTION

The primary S-054 data are solar X-ray images recorded on photographic film (SO212). A typical example is shown as Figure 1. The analysis of these images proceeds in two ways:

(i) visual inspection and interpretation to determine evolutionary histories, spatial distributions, structural geometries and correlations with other observations.

(ii) quantitative analysis whose purpose is to determine accurately the spatial variation of the emission from the corona. From this determination, the physical parameters of the plasma, i.e. temperature, density and pressure, can be obtained.

The first task is accomplished using photographic techniques, i.e. preparing prints and copies of the original negatives, while the second requires digitization of the images, followed by computer processing. However, there is considerable interplay between the two approaches. For instance, visual examination of the images plays an important role in the selection of problems for numerical analysis. Additionally, computer enhancement of the numerical images and subsequent display on a TV monitor can reveal structures by improving their relative contrast.

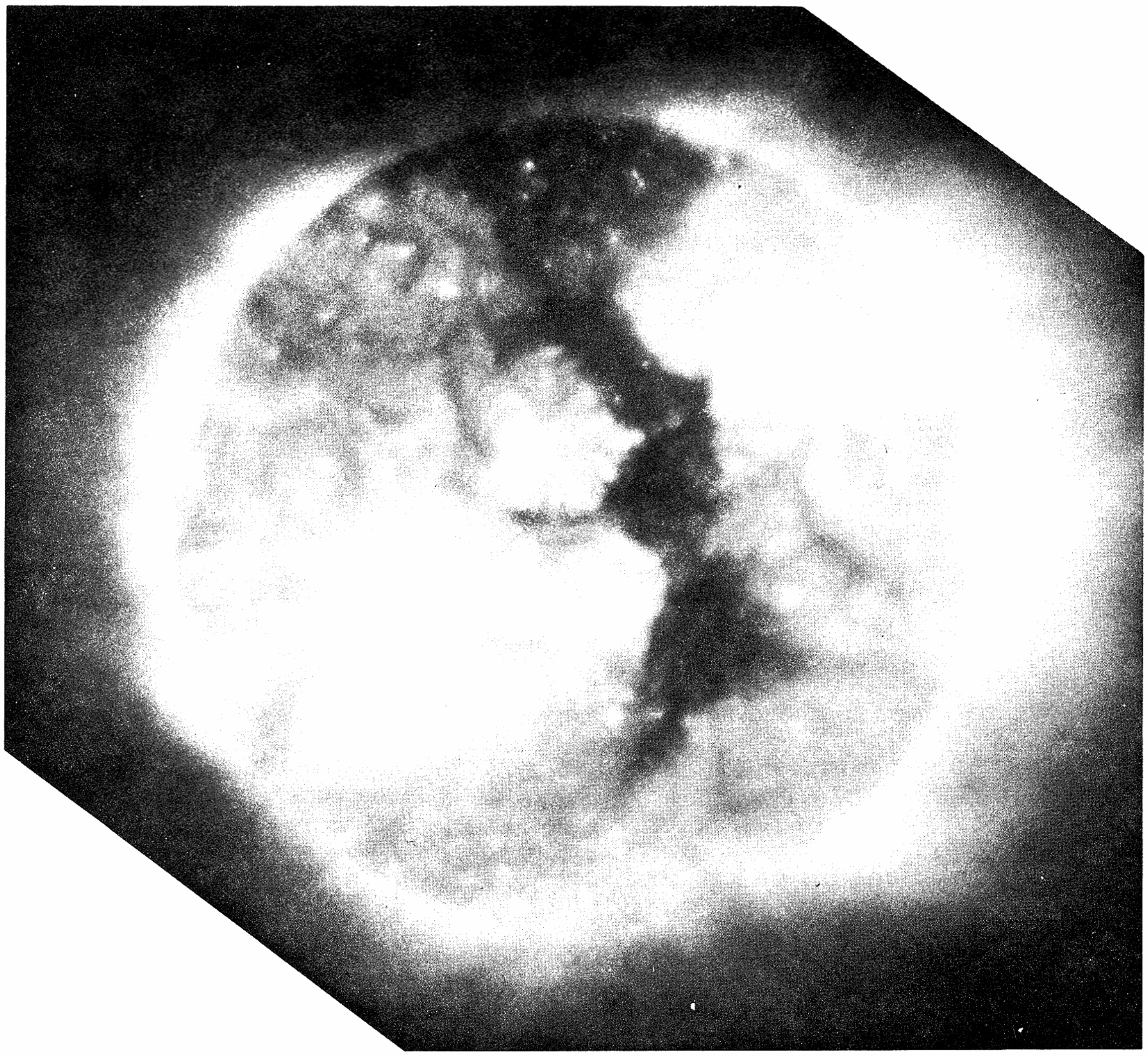
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Figure 1. A representative X-ray image of the solar corona taken during SL2 showing the types of structures which we observed.

In the following sections brief descriptions of the data reduction techniques are given.

2.1 Photographic Analysis

The objective of the photographic analysis effort is to prepare the data in forms suitable for scientific study. Following the development of the flight film at AS&E, the major effort in this area has been in the preparation of second and third generation copy films, prints, transparencies, ciné films and slides for scientific use. The operation is constrained by the need for preservation of the flight film.

The primary form of presentation is called an "interneg" which is a precisely enlarged positive transparency made directly from the flight film. The initial program envisioned a production of 7400 internegs which would include selected frames from each group of sun centered images. This goal has been over 91% completed.

The quick-look data are contact prints which are available as either fourth generation positives, printed on paper, or as third generation negatives suitable for projection. (A sample copy of this level of reproduction has been sent to the NSSDC for their approval for use in their archives.)

Interneg production is time consuming and it is impractical to reproduce all flight frames by that method. Consequently, we have developed a system for the production of second generation positive transparencies called mini-internegs. They will differ from true internegs only in the degree of enlargement. Their production will be semi-automatic and a program to reproduce all the flight frames will be implemented once the planned interneg production is completed.

Special data presentations are prepared and used extensively. These include ciné films to display temporal variations and multiple image slides and prints. The latter are useful in comparing related X-ray images or associated observations in other spectral regions.

2.2 Calibration

The S-054 coronal X-ray photographs can be analyzed quantitatively if the variation of the film response with incident energy over the appropriate soft X-ray wavelength region is known. To provide these data, a laboratory film calibration program using accurately measured fluxes of soft X-rays, having selected spectral characteristics appropriate to simulate solar coronal radiation, has been performed.

The data are recorded in the form of characteristic curves of photographic density vs. incident energy (HD curves). Some 150 HD curves have been produced so far, enabling quantitative calibration of the film response as a function of wavelength, for each of the five S-054 filmloads. The calibrations take into account the individual environmental history of each filmload, as well as the variations in development chemistry associated with the processing of each filmload.

The HD curves can be characterized by four parameters - the clear-film density, the maximum density, the contrast (γ), and the speed. The behavior of these quantities as a function of wavelength, etc., has been measured, and an analytic model developed for interpolating between measured points.

The film calibration program has proved quite successful; in most cases we now are able to calculate the energy deposited on the film with probable errors of less than 10%.

2.3 Image Digitization

Image digitization, or microdensitometry, is the starting point of the digital analysis. It consists of scanning the flight film with a narrow aperture (20 micron) photometer and recording the spatially resolved photographic density data on magnetic tape.

Once the operator has manually aligned the film fiducial mark with the optical axis of the microdensitometer, the scanning takes place under computer control. This allows additional information such as the aspect data to be incorporated so that all scans are performed in a uniform manner.

It has not been considered either necessary or feasible to scan all the X-ray images, and consequently images are scanned only on request. Approximately nine hundred images have been processed so far, representing approximately 20% of the eventual total.

2.4 Digital Analysis

The computer analysis system provides two major functions which can be identified as bookkeeping and scientific analysis. Bookkeeping consists of maintaining and updating records for each data frame. These records include experimental parameters such as the filter position, length of exposure, time of occurrence of the exposure and aspect information. These data were obtained from the diode array which accompanies each X-ray image and from the telemetry tapes. Processed image information is also recorded which includes the microdensitometer scanning parameters and the density to energy conversion. All the information is collected in a set of catalogues which enables the relevant information for each image to be accessed automatically.

Scientific analysis involves the manipulation of the scanned arrays. A typical sequence of events would involve conversion from photographic density to energy using the calibration data applicable to the particular film magazine, co-alignment of two energy images obtained from different filters, deconvolution to remove the effects of the point spread function of the X-ray optics, contouring in energy, division of image arrays to obtain spectral hardness indices, and finally recontouring to obtain the spatial variation of the temperature. The system is continually being extended as new analytical tasks become relevant to the scientific analysis.

2.5 Interactive Display

For those problems where the scientist wishes to influence the direction of the analysis closely, we have developed an Interactive Display System which can duplicate many of the functions of the main data analysis system in real time. For example, a scientist can display a scanned image on a TV monitor and, by varying the range of the grey scale, enhance the features in which he is interested. He can further use the display to deconvolve the images, produce contour maps or cross-sections, or make maps of the gradient of the displayed parameter.

In addition to the visual display, the system can output the results of its calculations to magnetic tape or produce hard copy grey scale images or contour plots. The system has been particularly useful in displaying the results of the 3-dimensional reconstruction program. The reconstruction is obtained with a cross-correlation technique which uses the rotation of the sun to provide different perspective views of the object. Finally, the facility is also used to test and debug the scientific programs which are to be incorporated into the main data analysis system.

3.0 SCIENTIFIC ANALYSIS

The following summary is limited to brief descriptions of those areas of the data which have been studied in detail up to this time.

3.1 Summary of Major Results

(a) Flares. Before Skylab, X-ray photographs (Krieger et al., 1971) and other techniques had indicated that active regions in the corona consist of one or more tubular structures anchored in regions of opposite magnetic polarity. Short bright structures of width less than 3500 km were observed to bridge the regions of maximum gradient in the longitudinal magnetic field. There is indication from the ATM data that, in some cases, the brightest of these core loops are the locations of flares (Petrasso et al., 1975). The results of this analysis indicate that the initial phases of a flare-like brightening in X-rays consists of the gradual brightening of a pre-existing loop structure and the sudden onset of rapid energy release at a small, restricted segment along the structure.

More generally, flare rises are seen to be characterized by the presence of one or more small bright features, which we have named Soft X-ray Kernels, with characteristic diameters of a few arc seconds (Kahler et al., 1975). Flare maximum and the decay phase are typically characterized by loop-like or diffuse structures with sizes ranging from those of kernels up to 60,000 km. The X-ray kernels represent a soft X-ray phenomenon characteristic of flare rise which had not been detected in previous observations with detectors of lesser resolution. They may be related to the H α and white light kernels which have been reported previously (Rust and Hegwer, 1975). We hope the soft X-ray observations will clarify the physical processes involved in the flare onset.

A detailed study of a flare on 9 August 1973, observed with the S-054 objective grating shows the existence of two distinct periods in the decay phase (Silk et al., 1975). During the initial decay, immediately after the peak of the X-ray flux, the distribution of emission measure as a function of temperature is changing with the high temperature portion decreasing with respect to the cooler portion. Within 1 - 2 minutes the distribution of emission measure becomes stable, although the total continues to decrease. Throughout the decay, the size of the high temperature kernel and of the cooler extended emitting region appear to be unchanged. The diminishing emission measure therefore corresponds to a loss of material from the flare, rather than expansion.

(b) Coronal Holes. The importance of coronal holes to the problem of mass balance in the corona was demonstrated before the ATM mission by work of Krieger et al. (1973), who pointed out the association between coronal holes and high speed streams in the solar wind. ATM data (Krieger et al., 1974; Nolte et al., 1975) have confirmed this association. Timothy et al. (1975) performed an initial analysis of the S-054 data on coronal holes showing, among other results, that coronal holes do not follow the conventional patterns of differential rotation with latitude. Instead, they seem to rotate almost rigidly. The large scale magnetic field pattern represented by the hole appears to arise from a particular arrangement of active region locations and from the evolution of the resulting remnant fields.

Simultaneous with the S-054 observations, Harvey at KPNO obtained spectroheliograms in the D_3 and 10830 Å lines of helium. Surprisingly, comparison of the X-ray and He observations showed that coronal holes were visible in the chromospheric He lines. An explanation of the visibility of coronal holes in these lines, such as those proposed by Zirin (1975) or Harvey et al. (1975), may contribute to understanding the processes of excitation and the distribution of abundances throughout the solar atmosphere.

(c) Bright Points. X-ray bright points were first seen in X-ray images obtained during a rocket flight in 1969 (Krieger et al., 1971).

Golub et al. (1974) found, from a preliminary analysis of the ATM data, that there were many more bright points than had previously been expected. Approximately 1500 emerge per day over the entire solar surface and their average lifetime is eight hours. They are associated with bipolar magnetic regions having typical fluxes of 10^{19} to 10^{20} Mx. Therefore, they carry as much magnetic flux to the solar surface (at this phase of the solar cycle) as do the active regions. Bright points were found to exhibit flaring behavior, with an estimated 15 percent of the points (over 200/day) flaring at some stage in their evolution. Unlike active regions, both bright points and bright point flares are observed at all latitudes from the equator to the poles.

A more recent study (Golub et al., 1975) has shown that the bright point distribution is not uniform. Rather, it shows systematic, statistically significant irregularities. The data have been interpreted in terms of a two component distribution, with approximately half of the bright points having uniform latitude and longitude distributions and the remainder confined mostly to $\pm 30^{\circ}$ in latitude and showing a very strong longitude dependence.

(d) Coronal Transients. The Skylab observations have revealed a new class of transient X-ray brightenings in the low corona, associated with $H\alpha$ filament disappearances, or "disparitions brusques." The time scale of the coronal events (3 - 40 hours) is considerably longer than in the chromosphere and the brightest X-ray events appear to be associated with the most rapid and complete filament disappearances. The initial X-ray brightening appears to be of the same size and location as the region of space previously occupied by the filament. The brightest events cause long-lived or permanent changes in the surrounding coronal structure.

Another class of transient brightening in the low corona outside of active regions is associated with flares. Although there were very few large flares during the Skylab period, the X-ray observations have revealed many flare-associated events in which a large cloud of material at coronal temperatures (~ two million degrees) appears to be ejected from an active region simultaneously with an erupting element or large surge. These clouds often fill a region on the order of half a solar radius long. Beneath such a cloud, at the footpoints of magnetic field lines stretching far from the active region, are observed chains of transient, flare-like brightenings in $H\alpha$. The propagation velocity of the clouds is ~ 100 km/sec. After initial establishment of the coronal cloud at high velocity, a slow expansion of the whole structure occurs at about 10 km/sec in the several cases studied.

(e) Loop Structures. The X-ray photographs show numerous coronal loop structures (Chase et al., 1975). Temperature and emission measure of the loops were calculated from film density measurements of the photographs and, under the assumption that the depth of emission is the same as the visible loop width, the absolute particle densities within the loops can be calculated. Typical loop temperatures range from 1.9 to 2.6 million degrees and the densities range from 10^9 to 2×10^9 electrons/cm^3.

Lifetimes of loops interconnecting separate active regions were studied. The results are complicated by the fact that loops are visible for only about 10 days out of the 27 day solar rotation period; however, the results show a wide range of lifetimes from one day to 50 days or more with a mean lifetime of about 10 days.

It has been found that loops interconnecting separate active regions tend to occur at the same active solar longitude for several solar rotations. Transequatorial loops at these active longitudes have been observed, confirming the fact established by Bumba and

Howard (1965) that "complexes of activity" extend across the equator during their development. While the existence of loop interconnections between close active regions appears to be almost a general rule, there are a few clear cases when even small distances are not bridged. The largest distance between two active regions bridged by an interconnecting loop that we could clearly see in the X-ray pictures was 37 heliographic degrees.

(f) Temperature Measurements. Temperature measurements can be made from the comparison of the energy transmitted by different filters. However, the calculations are involved and it is necessary to know the solar spectrum, the energy response of the film and various instrumental parameters. To check the validity of these calculations comparisons with spectroscopic data obtained from rocket flights during the Skylab mission have been made. The results have demonstrated good agreement between the two techniques (Davis et al., 1975) and have increased the confidence in the S-054 temperature measurements for times when no spectroscopic data are available.

3.2 Collaborations

In addition to the studies performed by AS&E scientists independently and with ATM investigators, it has been our policy to invite scientists from related disciplines to collaborate in the analysis of the data. Collaborations have been undertaken both with scientists who have observations which complement the S-054 data and with theoreticians whose primary goal is the description of the physics of coronal processes.

The primary areas of study have been

(i) the relation of the variation of the solar wind to the large scale coronal structures

(ii) observations of coronal holes in visible light wavelengths

(iii) the relation of the structures of active regions to the photospheric magnetic field

(iv) evolutionary histories of flares as seen in the X-ray images and with satellite born detectors

(v) comparison of the spatial location of the emitting regions in radio and X-ray wavebands and determination of the fraction of the radio flux arising from thermal bremsstrahlung

(vi) theoretical modeling of the heating of the corona above active regions

(vii) the stability of coronal loop structures

(viii) comparison of X-ray spectroscopic data with the S-054 images

(ix) comparison of large scale magnetic field patterns with coronal structures

(x) transient brightenings as seen in XUV and X-rays.

4.0 REFERENCES

Bumba, V. and Howard, R., 1965, Astrophys. J. 141, 1502.

Chase, R.C., Krieger, A.S., Švestka, Z., and Vaiana, G.S., 1975, 18th Plenary Session of COSPAR, Varna, Bulgaria, June 1975.

Davis, J.M., Gerassimenko, M., Krieger, A.S., and Vaiana, G.S., 1975, to be published in Solar Physics.

Golub, L., Krieger, A.S., Silk, J.K., Timothy, A.F., and Vaiana, G.S., 1974, Astrophys. J. Letters 189, L93.

Golub, L., Krieger, A.S., and Vaiana, G.S., 1975, Solar Phys. 42, 131.

Harvey, J., Krieger, A.S., Davis, J.M., Timothy, A.F., and Vaiana, G.S., 1975, Bull. AAS 7, 2, 358.

Kahler, S.W., Krieger, A.S., and Vaiana, G.S., 1975, to be published in Astrophys. J. Letters.

Krieger, A.S., Vaiana, G.S., and Van Speybroeck, L.P., 1971, in Solar Magnetic Fields, IAU Symp. No. 43, ed. R. Howard, p. 397.

Krieger, A.S., Timothy, A.F., and Poelof, E.C., 1973, Solar Phys. 29, 505.

Krieger, A.S., Timothy, A.F., Vaiana, G.S., Lazarus, A.J., and Sullivan, J.D., 1974, Proc. Third Solar Wind Conf. at Asilomar Conf. Grounds, California.

Nolte, J., Krieger, A.S., Webb, D., Vaiana, G.S., Lazarus, A.J., Sullivan, J.D., and Timothy, A.F., Abstract 5th Meeting of SPD of AAS, Boulder, 1975.

Petrasso, R.D., Kahler, S.W., Krieger, A.S., Silk, J.K., and Vaiana, G.S., 1975, to be published in Astrophys. J. Letters.

Rust, D.M. and Hegwer, F., 1975, Solar Phys. 40, 141.

Silk, J.K., Kahler, S.W., Krieger, A.S., and Vaiana, G.S., 1975, 18th Plenary Session of COSPAR, Varna, Bulgaria, June 1975.

Timothy, A.F., Krieger, A.S., and Vaiana, G.S., 1975, to be published in Solar Physics.

Zirin, H., 1975, Astrophys. J. Letters 199, L63.

SKYLAB APOLLO TELESCOPE MOUNT

S054

X-RAY SPECTROGRAPHIC TELESCOPE

Harvard College Observatory
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Cambridge, Massachusetts

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Foreword

This report from the Center for Astrophysics is intended to provide a summary of the data reduction and analysis and the interpretation of the results of the S-054 X-ray Telescope Experiment on Skylab.

The S-054 experiment is a joint effort between the Principal Investigator and his staff at the Center for Astrophysics and the Co-principal Investigator and his staff at American Science and Engineering. Since the overall effort on the data analysis and interpretation is conducted with the AS&E team, this report should be read in combination with the AS&E summary report.

All technical and scientific work between the two groups is closely coordinated, and the data reduction facilities at AS&E are at the complete disposal of our staff as defined in AS&E's contractual agreements with NASA.

This report is presented in seven parts. Part 1.0 is an introduction which briefly describes the experiment and the nature of the data. Part 2.0 is a report of the status of the primary and reduced data. Part 3.0 is a description of the techniques that we are using to analyze the data. Part 4.0 is a summary review of the scientific results obtained so far and a brief statement as to their relevance to current solar physics problems. Part 5.0 is a complete list of publications and presentations associated with the data analysis effort. Part 6.0 is a list of the scientific personnel involved in supporting the S-054 effort at the Center for Astrophysics.

A comprehensive list of on-going projects will be presented in the next report.

The S-054 effort has been supported at the Center for Astrophysics by NASA Contract NAS8-31017 with SAO from July 1, 1974 to December 31, 1974 and by NAS8-31374 with HCO from January 1, 1975.

A copy of this report has been submitted to the NSSDC as a guide for S-054 data users.

1.0 Introduction

The S-054 X-ray telescope on Skylab was a grazing incidence instrument, with an on-axis spatial resolution of the order of two arc seconds; the observed spectral range was 2 - 60 Å. Spectrographic data could be obtained in both low and high-resolution modes; low resolution spectral information was obtained by means of inserting one of six different filters into the optical path while higher resolution data could be recorded via the insertion of an objective grating. The latter mode was employed to obtain spectra of prominent bright X-ray sources, such as flare events. (See 1, 7, 15, 45 for further descriptions of the instrument.)

The eight-month long mission produced more than 32,000 images which ranged from 1/64 to 256 seconds in exposure length; the data are presently being reduced, analyzed and interpreted by a team at the Center for Astrophysics and at AS&E. The data reduction involves both the routine production of high-quality photographs and digitization of images into energy flux arrays; the analysis and interpretation involve the study of a number of carefully chosen topics, in particular morphological and quantitative analysis of selected coronal features, and the interpretation and comparison of the results in terms of either existing or developed theoretical models.

2.0 Status of Data

The primary data from the S-054 experiment consist of rolls of photographic film containing the X-ray images. This special un-supercoated, 70 mm Kodak SO-212 film was processed soon after each roll was returned from orbit, with special care taken toward removing the antistatic backing, transporting the film in the processing machinery, and controlling the uniformity of the development process. This was accomplished using specially designed equipment installed in the AS&E photographic laboratory.

The original film, consisting of five magazine loads (length about 1400 feet) with nearly 7000 frames apiece, and the calibration sensistrips are stored in a fireproof safe in a limited access area. They may be removed only by persons authorized by the Principal Investigator or Co-Principal Investigator and must be attended at all times and kept within designated areas when not in the safe. Approved activities involving the original film are limited to visual examination at a clean bench, microdensitometer scanning, numbering at a clean bench, copying on the contact printer, and enlarging on the Carlson precision enlarger.

The 70 mm film frame format contains, in addition to the X-ray image, a white light image, fiducial marks, and information on the time at the end of the exposure, the shutter duration time, the binary picture count, and the grating and filter configuration. Each frame has been numbered for identification and an entry made using this number in one of several computerized catalogs. This catalog now contains all the above information for each frame as well as the aspect information from the final IBM data tapes.

Other original data include photomultiplier and image intensifier count rates. These have been computer plotted from magnetic tape for the entire Skylab period, for such uses as temporal flare location.

From the original X-ray images one proceeds in two directions. These are photographic copying for morphological analysis and digitization of the images for quantitative analysis. Both are discussed in detail in Section 3. Here they will be only referred to in connection with the current status of the more systematically pursued aspects.

The 3N (third generation negative) copies in 70 mm roll format, for initial examination and selection of frames, have been produced for each magazine. Also internegs (enlarged 2P copies) for a large portion of the most useful exposures have been produced (see Figures 1a, b, c). A large amount of other photographic material (transparencies, enlarged prints, slides, movies, etc.) has been produced as requested by the individual investigators.

Image digitization by means of microdensitometer scans of the original film has been performed for about 900 frames. Selection has been tailored to the needs of individual studies to date. To utilize these data, a variety of computer programs that are easily accessible to the investigator has been installed in the AS&E computer system. These include cataloging, calibration, array manipulation, array display, deconvolution, and other programs for each phase of the data conversion and study. This system is nearly complete, although new applications are added when found useful, and is being utilized by various investigators. A small, dedicated computer with an associated television display and hard copy device is also presently available for use, with its system of programs nearly completed.

3.0 Data Reduction and Analysis

Two kinds of information are obtained from the X-ray images. These are qualitative descriptions of the images which related to the morphology and evolution of structures present in the corona, and quantitative results which provide numerical values for the physical parameters of the coronal plasma, such as temperatures and electron densities. A brief description of these morphological and quantitative analysis methods is given below.

3.1 Morphological Analysis

Visual inspection of X-ray images provides information on the three-dimensional structures present in the solar corona. The lifetimes of various features can be examined and their evolution described qualitatively as they cross the solar disc. The outline of flare structures can be determined and their evolution throughout the flare rise, flare fall, and post-flare phases can be determined.

Characteristic dimensions can also be obtained from the images. It is of considerable interest to know the range of sizes of X-ray active regions, coronal flux tubes, and structures associated with filaments and prominences.

Comparisons can also be made with other solar data. The X-ray features can be compared with ground-based magnetograms Hα, Ca K, etc. and with other space observations, such as the Skylab XUV, UV, and white light coronal data obtained simultaneously with the X-ray data.

In order to provide the photographic medium best suited for a particular scientific investigation, an extensive photographic facility was developed at AS&E under the S-054 program. Five major forms of photographic presentation are currently produced for these investigations. They are:

a. Contact reflection prints. The purposes of the reflection prints, high-quality "proof prints", are to give a subjective representation of the information content of the original images and to provide a "quick look" at the data for the selection of images for further photographic presentation.

b. Magnified (5x) images on transparent intermediate negative ("Interneg") film stock with an information content comparable to that of the original film. These enlarged 2P's (second generation, positive image) are used for detailed morphological studies.

c. Wide dynamic range, unity magnification, film copies. These are used with an optical viewer for evaluation of time variations, the lifetimes at various features, and for the detection of new coronal phenomena.

d. High-quality reflection prints (5x) produced from "Internegs". These presentations, because of the limitations of photographic paper, have a smaller dynamic range than presentations (b) and (c). However, the exposure and contrast may be selected to display a feature of interest in an optimum manner.

e. Motion picture films. These are used to illustrate the evolution of features or events, short-term structural changes, etc.

In addition a variety of special purpose presentations is produced as needed and as requested by the scientist. Figure 2 illustrates one type of presentation available. It is a sequence of images separated in time by a quarter of a solar rotation. It represents a synoptic view of the sun for the first five solar rotations of the Skylab mission. Proceeding down the first column, one can follow the evolution of the first coronal hole observed by Skylab. The long-term evolution of active regions can also be followed. In general, this type of presentation gives an overview of the appearance of the X-ray sun over an extended time period.

Figures 3 and 4 illustrate other types of photographic presentation used in morphological studies. They depict the development of an active region and its relationship to the photospheric magnetic field.

3.2 Quantitative Data Reduction and Analysis

The methods by which coronal plasma parameters, such as electron temperature and density as a function of position, are determined from the X-ray images will be discussed in this section. The discussion has been simplified in order to cover briefly the main methods employed.

The use of the X-ray telescope for quantitative coronal plasma diagnostics has to overcome all the complex problems connected with the calibration of the data. The broad wavelength dependent point response function, the wavelength dependence of the film response, and the broadband nature of the filters must all be considered in the reduction of the data. While quantitative data reduction requires much care and understanding of all possible sources of errors, we can confidently state that the many years of our calibration effort have resulted in our ability to derive electron temperatures and densities from the photographic data.

The X-ray images are scanned by a Photometric Data System Model 1010A microdensitometer with an aperture of 20 micrometers (2 arc seconds). The resulting digitized density arrays are stored on magnetic tape. Approximately one hour is required to scan the full solar disc. The density arrays are converted into digitized irradiance arrays (the distribution of energy per unit area per unit time deposited on the film) by means of the film calibration curves. A correction for radiation fogging is also applied. Since the film is wavelength dependent and the incident wavelength distribution is not known a priori, this procedure is an iterative one. In principle, these arrays should be deconvolved in order to remove the effects of telescope scatter. At the present time, deconvolution is done for special purposes since it is time consuming. Without deconvolution, in a number of cases, it is possible to obtain useful information about the temperature and density structure of various coronal features.

In order to relate the focal plane irradiance distribution to the coronal parameters, a quantitative relationship between the radiation emitted by the corona and that imaged by the telescope is required. This relationship is given by the following equation:

$$E_i = \frac{A}{4\pi f^2} \int_o^\infty \int_\lambda N_e^2(\ell)\ P(\lambda, T(\ell))\ \varepsilon_i(\lambda)\ d\lambda d\ell$$

where

E_i = power deposited on the film per unit area for an exposure through the ith filter

A = geometrical collecting area of the telescope = 42 cm^2

f = focal length of the telescope = 213 cm

N_e = electron density

ℓ = line-of-sight distance

$P(\lambda,T)$ = power emitted per unit wavelength interval per unit emission integral ($\int N_e^2\, dV$) at wavelength λ by plasma at temperature T, and

$\varepsilon_i(\lambda)$ = overall transmission function for the telescope including prefilter transmission, mirror reflectivity, transmission of the ith filter, and magazine window transmission. This function is determined from laboratory calibrations.

For the simple case of a uniform temperature along the line-of-sight, the above equation reduces to

$$E_i = \frac{A}{4\pi f^2} \left[EM\right] F_i(T)$$

where

$$EM = \int_0^\infty N_e^2(\ell)\,d\ell \quad \text{is the emission measure}$$

and

$$F_i(T) = \int_\lambda P(\lambda,T)\,\varepsilon_i(\lambda)\,d\lambda$$

Since the quantity $(A/4\pi f^2)$ $[EM]$ is constant for all filters, the ratio of the irradiances for two different filters

$$\frac{E_i}{E_j} = \frac{F_i(T)}{F_j(T)} \equiv R_{ij}(T), \text{ the spectral hardness index,}$$

is a function of temperature only.

Thus, from the ratio of the measured irradiances, the temperature can be determined independently of the emission measure. Once the temperature has been determined, the emission measure can be determined from the measured irradiance for any filter.

If the plasma column cannot be considered isothermal, we can still use the above expressions to define an "effective" temperature and emission measure; alternatively, we can assume a model for the line of sight dependence of the temperature and density.

In order to interpret the X-ray photographic data in terms of temperatures and emission measures by the above scheme, it is necessary to know $P(\lambda,T)$, the spectral distribution of the soft X-ray emission as a function of temperature T.

In our data analysis we use a modified version* of X-ray spectrum calculated by Tucker and Koren† for the function $P(\lambda,T)$. These investigators have calculated the 0.5 - 70 Å X-ray spectrum of a low-density plasma having electron temperatures in the range 6×10^5 to 10^8 °K and elemental abundances equal to those generally believed to exist in the solar corona.

Figure 5 is a block diagram illustrating the steps employed to obtain quantitative information from the X-ray photographs. The starting point is the microdensitometry of images taken through two filters at several exposure times. The filters selected at the present time are usually 1 and 3. The exposures are selected to be as close in time as possible to minimize the effect of misalignment due to changes in ATM pointing and changes in the physical parameters with time.

We have found that we can relate the net density on the film to the power per unit area deposited on the film E_i by means of a semi-empirical relationship with three free parameters:

$$D_i = f(D_{max}, \gamma_i, (a\mu)_i, E_i t)$$

where

D_{max} = maximum net density attainable,

γ_i = the slope of the linear portion of the log $E_i t$ vs. D_i curve.

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* New cross-section data, results of ionization equilibrium calculations, and updated solar abundances are continuously inserted into the spectrum calculation program.

† Tucker, W.H. and Koren, M., 1971, Astrophys. J. 168, 283.

$(a\mu)_i$ = film speed parameter, proportional to the reciprocal of the energy at which the net density equals zero, and

t = the exposure time.

For the purposes of this discussion, the actual functional form of the relationship is not necessary. D_{max} is obtained experimentally; γ_i and $(a\mu)_i$ are wavelength dependent and, therefore, are functions of the temperature and are not known a priori. An iterative method is used to find their values.

A trial γ_i and $(a\mu)_i$, γ_i' and $(a\mu)_i^o$, respectively are used to convert density arrays at several exposure times to power per unit area arrays E_i' for a restricted area of the sun. A "scatter plot" is now produced by plotting point by point the E_i' for one exposure time vs. the E_i' for another exposure time, usually a factor of four longer than the former exposure. If the density-to-energy conversion used is correct, all points should fall on a straight line with a slope of unity. If they do not, a new γ_i can be found from the slope of the best-fit straight line in the region of the "scatter plot", where the density-to-energy relationship is linear for both exposures. This procedure is repeated until no further improvement in the "scatter plot" is obtained. This metod determines the best γ_i independently of the choice of $(a\mu)_i^o$. The final γ_i and the original $(a\mu)_i^o$ are used to determine a new array E_i^o.

From the above form of the expression relating D_i to E_i, we notice that the parameter $(a\mu)_i$ only enters in as a product with E_i. Thus for a given density D_i the following is true

$$(a\mu)_i^o \, E_i^o \;=\; a\mu_i(T)E_i(T)$$

where $a\mu_i(T)$ is the correct film speed for an incident radiation spectrum characterized by the temperature T and $E_i(T)$ is the correct power per unit area deposited on the film.

$a\mu_i(T)$ is assumed to be given by the following expression

$$a\mu_i(T) = \frac{\int_\lambda a\mu(\lambda)\ P(\lambda,T)\ \varepsilon_i(\lambda)\ d\lambda}{\int_\lambda P(\lambda,T)\ \varepsilon_i(\lambda)\ d\lambda}$$

where $a\mu(\lambda)$ is the laboratory determined film speed parameter for monochromatic radiation of wavelength λ and the other quantities are as previously defined.

Thus for two filters, say 1 and 3, we have

$$(a\mu)_3^o\ E_3^o = a\mu_3(T)\ E_3(T)$$

$$(a\mu)_1^o\ E_1^o = a\mu_1(T)\ E_1(T)$$

Dividing the first equation by the second, we obtain

$$\frac{(a\mu)_3^o\ E_3^o}{(a\mu)_1^o\ E_1^o} = \frac{a\mu_3(T)}{a\mu_1(T)} \cdot \frac{E_3(T)}{E_o(T)}$$

Now $E_3(T)/E_1(T) = R_{31}(T)$, the spectral hardness defined previously, and so we have finally

$$\frac{(a\mu)_3^o\ E_3^o}{(a\mu)_1^o\ E_1^o} = \frac{a\mu_3(T)}{a\mu_1(T)}\ R_{31}(T) \equiv \varrho_{31}(T)$$

a function of T only and which is derived from the theoretical solar spectrum and laboratory calibration data.

Hence, once we have found the ratio on the left-hand side of the above equation from the iterative procedure for γ outlined above, the temperature is given by that value of T which yields a Q_{31} equal to that ratio.

From the value of T found above we can now find $E_i(T)$, e.g.

$$E_3(T) = \frac{(a\mu)_3^o \, E_3^o}{a\mu_3(T)}$$

The emission measure is given by

$$\int N_e^2 \, d\ell = \frac{E_3(T)}{F_3(T)} \cdot \frac{4\pi f^2}{A}$$

Figure 6 gives an example of this procedure for an active region.

4.0 Scientific Interpretation and Significance of Results

The data base generated by the S-054 X-ray telescope provides an opportunity to study the details of the complex of phenomena that take place in the sun's atmosphere, as well as to begin the construction of a coherent picture of the interrelations existing between various coronal structures. The degree of spatial, spectral, and temporal resolution achieved allows modeling of the features that are the corona -- active regions, flares, active region interconnections, filaments and filament cavities, bright points, and coronal holes. The ultimate goal, always kept in mind, is, of course, to understand solar activity and dynamics.

The fundamental result which emerges from the analysis which has been done is that there is no quiet, homogeneous corona; the view that the corona is dominated by structures, which appear to related to a continuum of levels of activity, has been reenforced, and solar activity is seen to correlate strongly with the solar magnetic field. Thus the corona must be viewed as a complex system whose individual parts are strongly interacting and, therefore, cannot be studied in isolation (2, 5, 15, 54, 56).

The time resolution achieved in particular allows the observation and study of the restructuring of coronal features, and hence of the coronal magnetic field on both a long and short-term basis (3, 12); that is, it is possible to examine the extremes of time scales from transient events, such as flares, to changes occurring with periods characteristic of the solar rotation, such as the evolution and decay of whole structures.

The analysis accomplished up to now allows us to reach some very general conclusions and suggests fertile new paths for further investigations. It is now clear that the majority of coronal structures has closed-loop configurations whose footpoints appear to be anchored in regions of opposite magnetic polarity. Comparison of loop structures with potential field extrapolations of photospheric magnetic fields strongly suggests that the former outline, to some approximation, the three-dimensional configuration of the coronal magnetic field (21, 37). The dynamics of the coronal plasma must thus be understood within the context of loop configurations; homogeneous models are clearly insufficient.

The understanding of mass and energy balance in the solar corona certainly occupies a central place in the overall problem that must be solved; that is, we must answer the question of how the loop structures are maintained energetically. Traditional coronal heating theories tend to deal with homogeneous geometries; the inhomogeneous structuring of the corona with the concomitant implications for heat conduction, radiation and energy deposition force a reexamination of the traditional point of view.

Related to the energetics problem and quite inseparable, is the question of the nature of the dynamics which determines the topology of the structures. In this category fall questions relating to the formation, stability, and evolution of loop-like features. The roles of force-free fields, magnetic field merging and annihilation, formation and dissipation of current sheets, and microscopic as well as macroscopic (MHD) instabilities are all still unresolved, and in fact might constitute the bridge connecting the energetics with the dynamics. The placing of these activities within the context of loop structures appears to be the thematic concern of future inquiry.

4.1 Flares

The study of solar flares can be broken down into a sequence of smaller, not necessarily independent, subjects. Thus, we concern ourselves with the nature (and existence) of the preheating phase, the discrimination between possible chromospheric or coronal origins of flaring, the localization of the triggering point with respect to the magnetic field geometry, the determination of the physical parameters -- temperature, density, field strength -- before, during, and after flaring, and finally the effects of the flare on its surroundings.

The data analysis proceeds along two parallel lines: the first consists of a statistical study of many events of a particular type; in this way general morphological properties of selected physical configurations are elucidated. The second consists of a detailed study of particular events in which the high spatial, spectral and temporal resolution provided by the data base is put to work; the goal here is to obtain the detailed physical properties of the selected events.

The results of the work done up to now can be summarized as follows:

1. Two basic structures have been identified during the course of flaring events (34, 39):
   a. X-ray "kernels", which are small, point-like ($\simeq$10") brightenings most prominent during the rise phase; whether these kernels are related or not to possible non-thermal events is a subject of present investigation.
   b. Loop-like structures, which become evident primarily during the maximum and decay phases but are present at all times. They constitute the basic structural element for understanding the X-ray event from preflare brightening to post-flare configuration.

2. Pre-existing loop structures appear to brighten before the onset of flaring; this result indicates the possible existence of a preheating phase (35, 44).

3. The detailed spatial and temporal studies indicate the following flare characteristics (12, 18, 22, 44):

   a. Spatial comparison of the site of initial soft X-ray release and the pre-existing loop indicates that only a restricted section of the loop, at coronal levels, contributes to the flaring volume (35, 38).

   b. The volume from which most of the energy is radiated changes relatively little (< 3x) during the flare evolution. The implication is that radiative losses play a significant role in the flare energy budget, in particular when compared with possible cooling by conduction or expansion.

   c. Comparison of the sites of X-ray emission with the magnetic field configuration shows that emission is concentrated near the neutral line of the longitudinal magnetic field; the brightest structures, at flare onset, appear to bridge the neutral line.

   d. The restructuring of the core of the flare coincides in time with the occurrence of possible non-thermal events.

   e. The study of different spatial structures during flaring has shown that each has its own, quite distinct, light curve (44); thus, the complex flare structure may consist of a collection of arches, each with its own distinct temperature and density distribution, and temporal evolution

(9, 29, 40). Further, the decay phase is structurally dominated by loop systems; low, compact loops are apparent at the peak of the event, whereas more and more extended, high loops become prominent during the fall phase. These observations are clearly relevant to the construction of flare cooling models.

f. Similar sorts of results, indicating isolated temperature regions, are given by the spectroscopic data (40).

4.2 Active Regions

A large fraction of the solar coronal soft X-ray emission comes from active regions (AR); the study of this emission can be considered as a problem which will further our understanding of solar activity. Since the X-ray structures appear to be determined to a great extent by the magnetic field, the evolution of AR's provides a clue to the evolution of the solar magnetic field (46, 48, 15, 54, 55, 57, 58).

The study of AR's, therefore, focuses on both the nature of their detailed structure and structural changes and on the overall evolution of these structures. The analysis being done at the present time can be categorized as follows:

1. The three-dimensional structure of an AR is investigated by means of sequences of observations taken at discrete intervals during the passage of an AR across the solar disc. In addition the temporal evolution of an AR and its association with the concurrent evolution of the solar magnetic field is examined.
2. The physical parameters which characterize an AR are determined via the comparison of the soft X-ray images with spectrographic data obtained by rocket-borne instruments.

3. The great breadth of the data base in time allows one to distinguish between processes characterized by a wide range of time scales of activity. The relationship between transient events and evolutionary changes can thus be found.

4. Static models which are derived from the data and that require a balance between the energy input and losses, are constructed.

The preliminary results may be summarized as follows:

1. As seen in X-rays, coronal AR's take the form of complexes of closed tubular structures, loosely called "loops", connecting regions of opposite magnetic polarity within the same or adjacent plage regions; these loops have a wide range of characteristic sizes. AR's are not isolated structures, but rather relate to, and are connected with, surrounding lower-activity (quiescent) regions, as well as other AR's. Studies of the detailed structure, characteristic physical parameters, and evolution of interconnected regions are proceeding (30).

2. A key observation appears to be the strong association of regions of high temperature with regions of high density. This correlation of temperature and density places strong constraints on the modeling of coronal heating and cooling (13, 36, 57, 58, 23).

3. Calculated radiative cooling times, as well as conjectured conductive cooling times, are all smaller than the characteristic lifetimes of structures. The implication is that substantial energy deposition must occur over extended periods of time, not just impulsively. Again, this result constrains the range of possible heating models. In addition, it appears

that radiative losses must play a significant role in the overall energy balance.

4. Two quite different time scales of activity have been discerned:
   a. Short-term changes (hours to days) are likely to be related to photospheric magnetic field changes. During the course of such activity, the overall topology of the X-ray structures remains essentially the same.
   b. Long-term (∿ several solar rotations) activity corresponds to significant changes in the large-scale structure of AR's. These changes seem to be related to the evolution of the overall AR due to the emergence, development, and decay of magnetic flux.

5. The structuring of an AR correlates strongly with the structure of the magnetic field (21, 37).
   a. The compact portion of an AR is spatially correlated with steep magnetic field gradients perpendicular to neutral lines; that is, there exists a qualitative spatial correspondence between regions of enhanced X-ray emission and calculated magnetic field configurations, extrapolated to coronal levels using current-free calculations. There is evidence for the importance of coronal currents; therefore, calculations are being extended to incorporate current-carrying fields.
   b. The decay of the magnetic fields seems likely to be related to the breakdown of magnetic confinement and the evolution of AR's into large-scale structures (LSS), that is, the inner quiescent corona (50, 51, 80, 83) (57, 58, 28, 51). Hence work is being done on the evolution of AR's via the spreading,

weakening, and merging into large-scale features; the interaction between the evolving AR and a newly emerging AR is a significant complicating feature. There is a suggestion that coronal holes represent the final stage of LSS evolution when the topological configuration is favorable (33).

4.3 Coronal Holes

Coronal holes (CH) are features which are defined by what they lack: emission. They are regions virtually devoid of emission, bounded by what appear to be divergent large-scale loop structures. Since they were observed before the launching of the ATM, evidence had already accumulated which suggested a possible association between CH's and high-speed solar wind streams (8, 41). It was, therefore, known that CH's might play a significant role in the overall mass balance in the corona.

The analysis of the S-054 data, in conjunction with other observations, has yielded the following preliminary results (4, 7, 23):

1. The magnetic field inside a CH is predominantly of one sign. Analysis indicates that the particular large-scale field pattern represented by the CH is formed wherever the successive emergence of active region fields results in a swath of unipolar field extending across the equator, and at times reaching the poles, and bounded by opposite polarity fields (10, 33, 23).
2. The observation of loop structures appearing to arch away from the CH, as mentioned above, suggests that the CH is associated with divergent field configurations. This suggestion, in conjunction with the association with high-speed solar wind streams,

has strong implications for theories of solar wind acceleration.

3. One expects the form, and hence the stability, of CH's to be affected by the diffusion of remnant AR fields, the emergence of new, perturbing fields, and the differential rotation of the solar surface. The observation that CH's do not follow the differential rotation pattern as, for example, defined by the sun spots, and instead appear to rotate far more rigidly (33) is, therefore, a totally new and unexpected result. This observation is relevant to a range of theories from accounts of the role of the solar magnetic field, to models for solar convection.

4. The comparison of the X-ray data with spectroheliograms of the D_3 and 10830 Å lines of helium has shown a strong association between the CH as defined in the X-ray images, and helium structures. Here is a clear opportunity to investigate the nature of the mechanism of helium excitation on the sun (11, 42).

4.4 Bright Points

Bright points (BP), first discovered on a pre-ATM rocket flight, may be defined as small (< 30" diameter) compact regions of enhanced X-ray emission, associated with compact bipolar magnetic field regions. There is a certain resemblance to (the far larger) AR, but the preliminary data indicate that they form a distinct category of solar atmospheric features. Some, but not all, BP's appear to have a very compact (< 10" diameter) core. Their average lifetime is of the order of 8 hours; their maximum area appears to vary with time. The range of values observed for the area, lifetime, and emergence rate suggests a possible connection between BP's and the supergranulation pattern (6, 26, 32). The primary results of the investigation to date are (2, 5, 6, 16, 19):

1. There exists a very large number of BP's on the solar disc. The total population appears to consist of a uniformly random (in latitude and longitude) component extending to the poles, and an inhomogeneous component which seems to lie in the more active latitudes and is non-uniform in its longitudinal distribution (43, 32). There is a strong suggestion that the latter component, but <u>not</u> the former, is related to the AR's whose latitude distribution it resembles.
2. Approximately 10% of the BP's exhibit flaring behavior; the surface brightness is seen to increase an order of magnitude within the span of $\sim$ 10 minutes. This is a characteristic which some BP's appear to share with AR's. However, the existence of the above-mentioned uniform component in the BP population indicates that BP's are not just small AR's; perhaps their association with supergranulation cells is a key to the understanding of their origin.
3. There is some evidence, not yet conclusive, that BP's contribute as much or more to the total solar magnetic flux as AR's (57). If verified, this is an important result from the point of view of theories of magnetic field activity; the implications of the uniform component for solar dynamo theories are particularly striking.
4. The yet unpublished discovery of temporally coherent changes in the BP spatial distribution with coherence lengths of the order of the solar radius, is too recent to permit a sensible account

of its possible significance. One might mention here that this result is a possible indication of spatially coherent, large-scale structures underlying the visible layers of the sun.

4.5 Models and Theoretical Work

Until the advent of recent XUV and X-ray observations of the solar corona, theoretical models of the physics of the solar atmosphere were fundamentally restricted to simple, spherically-symmetric, or plane-parallel geometries; presumed coronal structures had, by necessity, clearly speculative elements. The recent flood of detailed data, in conjunction with the ongoing reduction and analysis, has given a natural impetus to theoretical efforts designed to elucidate the great structural complexity of the corona which has now become so evident. These efforts aim at an understanding of observed density and temperature variations, energetic balance and (in-) stability, and finally the temporal development of regions of varying levels of activity. Below follows a very brief summary of the ongoing theoretical investigations; the unifying approach has been to correlate the MHD/fluid and microturbulent aspects of the coronal plasma.

The starting point of our efforts has been to provide a basis for deriving density and temperature information from the X-ray data. A detailed study of the compact portions of active regions (36) has provided ranges of the characteristic physical parameters, including typical physical dimensions; this model considered the active region core a hemisphere, with no internal structure, as a first approximation. A refinement of this work, which regards active regions as assemblages of loop-like structures, is proceeding at the present time; the detailed implications of the loop geometry for quasi-static energy balance and long-term evolution are investigated by solving the energy transport equation within loops. Loop models have been parametrized so as to allow study of the relative importance of conductive and radiative cooling, as well as of the modes of energy deposition.

Extending the above loop structure work to the problem of loop heating has been the aim of a study by our group and collaborators; central to this work is the contention that coronal heating can only be understood within the context of the loop structures. The data strongly suggests the viability of heating mechanisms other than wave dissipation. We examine in some detail the geometry, energetics, and dynamics of various current-sheet dissipation models, with emphasis upon the role of turbulence in both energy deposition and transport. As an alternative we plan to investigate the coupling of sound and Alfven waves, along with the possibility of subsequent wave dissipation in the weakly turbulent limit. Emphasis is placed upon confronting sufficiently detailed models with the observations so as to distinguish between the various mechanisms.

In a similar vein, the study of energy transport within loops has led to an examination of possible associated instabilities. For example, the strong temperature dependence of thermal conduction has suggested the possibility of thermal condensation within loops; work on the competing time-dependent effects of radiative cooling and conduction, demonstrating the basic effect, has been carried out (Compagno, thesis Palermo 1975), and more detailed studies are planned. The consequences of impulsive changes in the loop-heating function, in particular with regard to the observed sudden loop brightenings, form a related ongoing area of investigation (G. Peres, thesis).

Finally, the growing awareness of the importance of weak microturbulence in dissipative processes within the solar corona has led us to consider the possibility and consequences of strong plasma turbulence. Preliminary work suggests that the strong microfields occurring as a result of soliton formation within a strongly turbulent plasma play a significant role in stochastic particle acceleration; the relationship between rapid turbulent energy dissipation and relativistic particle acceleration, possibly in the solar flare context, is the focus of further study.

5.0 Personnel

The general philosphy has been to keep at a minimum the permanent scientific staff while at the same time allowing ample room for visiting scientists, guest investigators, and other collaborators on a temporary basis. The administrative support is limited to a permanent administrative secretary and to temporary help from the administrative office at the Center for Astrophysics. Technical supporting work and computer use, in addition to that provided by AS&E, has come on an as-needed basis.

Permanent Staff

Giuseppe S. Vaiana	Principal Investigator
Martin V. Zombeck	Senior Project Scientist
Charles W. Maxson	Data Manager
Robert Rosner	Scientist
Betty Duncan	Administrative Secretary

Associates, Visiting Scientists, Resident Guest Investigators, and Other Collaborators have included:

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6.0 Bibliography

Publications

1 Vaiana, G.S.
Methods of imaging X-ray astronomy and the X-ray spectro-heliograph on ATM
1974, CNES Space Optics, Proc. of Summer School on Space Optics Marseilles, 29 June-4 July, ed Marechal & Courtes, Gordon & Breach

2 Vaiana, G.S., J. Davis, R. Giacconi, A. Krieger, J. Silk, A.F. Timothy & M. Zombeck
X-ray observation of characteristic structures and time variations from the solar corona - Prel. results from Skylab
1973, Ap.J. 185, L47

3 Vaiana, G.S., A. Krieger, J. Silk, A. Timothy, R. Chase, J. Davis, M. Gerassimenko, L. Golub, S. Kahler & R. Petrasso
Dynamic events in the X-ray corona (Progress Report from ASE X-ray telescope on Skylab)
1974, Coronal Disturbances, Proc. IAU Symp 57, ed. Newkirk, D. Reidel, Holland, 461

4 Vaiana, G.S.
La corona solare in raggi X
1974, Annuario Scienza e Tecnica, ed. Mondadori, Milano, p. 279

5 Vaiana, G.S. and W. Tucker
Solar X-ray emission
1974, Chap. 5, X-ray Astronomy, ed Giacconi and Gursky, D. Reidel, Boston

6 Golub, L., A. Krieger, J. Silk, A.F. Timothy & G.S. Vaiana
Solar X-ray bright points
1974, Ap.J. 189, L93

7 Vaiana, G.S., A.S. Krieger, R. Petrasso, J. Silk & A.F. Timothy
The X-ray spectrographic telescope
1974, in Instrumentation in Astronomy-II, 44 of Seminar Proc. ed L. Larmore & D. Crawford, Soc. of Photo-optical Instrumentation Engineers, 185

8 Krieger, A.S., A.F. Timothy, G.S. Vaiana, A. Lazarus, S. Sullivan
X-ray observations of coronal holes and their relation to high-velocity solar wind streams
1974, Proc. of 3rd Solar Wind Conf., Asilomar Conf. Grounds, Pacific Grove, Calif. ASE Preprint #3539

9 Silk, J.K., S.W. Kahler, A.S. Krieger, A.F. Timothy & G.S. Vaiana
Objective grating studies of X-ray flare spectra, 1975
Skylab Solar Workshop (March 21-22, 1974), Oss. and Mem. Osservatorio Arcetri #104, ed. G. Righini, p. 143.

10 Timothy, A.F., M. Gerassimenko, L. Golub, A. Krieger, R. Petrasso and G.S. Vaiana
Long-term development of the large-scale corona and the evolution of coronal holes, 1975
Skylab Solar Workshop (March 21-22, 1974), Oss. and Mem. Osservatorio Arcetri #104, ed. G. Righini, p. 93.

11 Harvey, J., A.S. Krieger, A.F. Timothy & G.S. Vaiana
Comparison of Skylab X-ray and ground based helium observations
1975, Skylab Solar Workshop (March 21-22, 1974), Oss. and Mem. Osservatorio Arcetri #104, ed. G. Righini, p. 50.

12 Pallavicini, R., S.W. Kahler, A.S. Krieger, J.K. Silk & G.S. Vaiana
X-ray and radio emission for the June 15, 1973 solar flare
1975, Skylab Solar Workshop (March 21-22, 1974), Oss. and Mem. Osservatorio Arcetri #104, ed. G. Righini, p. 157.

13 Landini, M., B. Monsignori-Fossi, A. Krieger & G.S. Vaiana
Model of coronal active region
1975, Skylab Solar Workshop (March 21-22, 1974), Oss. and Mem. Osservatorio Arcetri #104, ed. G. Righini, p. 59.

14 Landini, M., B. Monsignori-Fossi
Coronal active region evolution
1975, Skylab Solar Workshop (March 21-22, 1974), Oss. and Mem. Osservatorio Arcetri #104, ed. G. Righini, p. 67.

15 Vaiana, G.S., R. Chase, J. Davis, M. Gerassimenko, L. Golub, S. Kahler, A.S. Krieger, R. Petrasso, J.K. Silk, R. Simon, A.F. Timothy, D. Webb, and M. Zombeck
1975, Skylab and the ASE X-ray Telescope Experiment: A New View of the X-ray Corona, Skylab Solar Workshop (March 21-22, 1974), Oss. and Mem. Osservatorio Arcetri #104, ed. G. Righini, p. 3.

15a Poletto, G., A.F. Timothy, A.S. Krieger, and G.S. Vaiana
Coronal X-ray Structures and Coronal Magnetic Fields
1975, Skylab Solar Workshop (March 21-22, 1974), Oss. and Mem. Osservatorio Arcetri #104, ed. G. Righini, p. 175.

15b Compagno, G.
Coronal Magnetic Flux Tubes
1975, Skylab Solar Workshop (March 21-22, 1974), Oss. and Mem. Osservatorio Arcetri #104, ed. G. Righini, p. 74.

16 Timothy, A.F., L. Golub, A. Krieger, J. Silk, G.S. Vaiana
Solar X-ray Bright Points
1974, Bull. AAS, 6,265

17 Krieger, A.S., M. Gerassimenko, R. Petrasso, A.F. Timothy
The evolution of the coronal structure of an active region
1974, Bull. AAS, 6, 265

18 Vaiana, G.S., S. Kahler, A. Krieger, R. Pallavicini, J. Silk
An X-ray flare from Skylab: Results and interpretation
1974, Bull AAS, 6, 265

19 Golub, L., R. Chase, A. Krieger, J. Silk, A.F. Timothy, G. Vaiana
Coronal bright points
1974, Bull. AAS, 6, 287

20 Krieger, A.S., L. Golub, J. Silk, A.F. Timothy, G.S. Vaiana, D. Webb
Temporal behavior of the coronal structure of active regions
1974, Bull. AAS, 6, 290

21 Poletto, G., A. Krieger, J. Silk, A.F. Timothy, G.S. Vaiana
Extrapolation of photospheric magnetic fields into the corona
1974, Bull. AAS 6, 292

22 Silk, J.K., S. Kahler, A. Krieger, A.F. Timothy, G. Vaiana, R. Pallavicini
An experimental model of solar flares in the corona
1974, Bull. AAS, 6, 294

23 Timothy, A.F., A. Krieger, R. Petrasso, J. Silk, G.S. Vaiana
The evolution of coronal holes
1974, Bull. AAS, 6, 295

24 Vaiana, G.S., M. Gerassimenko, A. Krieger, A.F. Timothy, M. Landini & B.C. Monsignori-Fossi
Temperature and density of the coronal portion of an active region
1974, Bull. AAS, 6, 296

25 Krieger, A.S., R. Chase, M. Gerassimenko, S. Kahler, A.F. Timothy, G.S. Vaiana
Time variations in coronal active regions
1974, to be pub. in Proc. of IAU-COSPAR Symp. #68, Buenos Aires, Argentina

26 Golub, L., A. Krieger, J. Silk, A.F. Timothy, G.S. Vaiana
Time variations of solar X-ray bright points
1974, to be pub. in Proc. IAU-COSPAR Symp. #68, Buenos Aires

27 Kahler, S.W., A. Krieger, J. Silk, R. Simon, A.F. Timothy, G.S. Vaiana
Studies of the dynamic structure and spectra of solar X-ray flares
1974, to b pub. in Proc. IAU-COSPAR Symp #68, Buenos Aires

28 Krieger, A.S., R. Petrasso, J. Silk & G.S. Vaiana
The structure and dynamics of the quiet X-ray corona
1974, to be pub. in Proc. of COSPAR Intl. Symp. on Solar-Terrestrial Physics, Sao Paulo, Prazil

29 Silk, J.K., S. Kahler, A. Krieger, A.F. Timothy, D. Webb, G.S. Vaiana
Spatial and spectral observations of two solar X-ray flares
1974, to be pub. in Proc. of COSPAR Intl. Symp. on Solar Terrestrial Physics, Sao Paulo, Brazil

30 Chase, R.C., L. Golub, A. Krieger, J. Silk, G.S. Vaiana, M. Zombeck, A.F. Timothy
Temperature and density measurements of coronal loops
1975, Bull. AAS, 7, 346

31 Germassimenko, M., J. Davis, R. Chase, A. Krieger, J. Silk, G. S. Vaiana
Simultaneous X-ray spectra and X-ray images of an active region
1975, Bull. AAS, 7, 347.

32 Golub, L., A. Krieger, R. Simon, G. Vaiana, A.F. Timothy
Temporal and spatial properties of coronal bright points
1975, Bull. AAS, 7, 350.

33 Timothy, A.F., A.S. Krieger, G.S. Vaiana
The Structure and Evolution of Coronal Holes
1975, Solar Physics 42, 135.

34 Kahler, S.W., A.S. Krieger, G.S. Vaiana
Morphological evolution of X-ray flare structures from the rise through the decay phase
1975, Ap.J. Letters, 199, L57.

35 Petrasso, R.D., S.W. Kahler, A.S. Krieger, J.K. Silk
The location of the site of energy release in a solar X-ray subflare
1975, Ap.J. Letters, 199, L127.

36 Landini, M., B.C. Monsignori-Fossi, A. Krieger, G.S. Vaiana
The coronal structure of active regions
1975, submitted to Solar Phys. (Center for Astrophysics Preprint No. 343).

37 Poletto, G., G.S. Vaiana, M.V. Zombeck, A.S. Krieger, A.F. Timothy
A comparison of coronal X-ray structures of active regions with magnetic fields computed from photospheric observations
1975, submitted to Solar Phys. (Center for Astrophysics Preprint No. 342).

38 Petrasso, R.D., S. Kahler, A. Krieger, J. Silk, G.S. Vaiana
The location of the site of energy release in an X-ray subflare
1975, Bull. AAS, 7, 352.

39 Kahler, S.W., A. Krieger, G.S. Vaiana
General properties of soft X-ray flare images
1975, Bull. AAS, 7, 355.

40 Silk, J.K., S. Kahler, A. Krieger, G.S. Vaiana
Time changes in the structure and spectrum of an X-ray flare.
1975, Bull. AAS, 7, 355.

41 Nolte, J., A. Krieger, D. Webb, G.S. Vaiana, A. Lazarus, J. Sullivan, A. F. Timothy
The coronal source of recurrent, high speed solar wind streams
1975, Bull. AAS, 7, 358.

42 Harvey, J.W., A. Krieger, A.F. Timothy, G.S. Vaiana
Comparison of Skylab X-ray and ground-based helium observations
1975, Bull. AAS, 7, 358.

43 Golub, L., A.S. Krieger, G.S. Vaiana
<u>Observation of a nonuniform component in the distribution of coronal bright points</u> (Research note)
1975, Solar Phys., <u>42</u>, 131.

44 Pallavicini, R., G.S. Vaiana, S.W. Kahler, A.S. Krieger
<u>Spatial Structure and Temporal Development of a Solar X-ray Flare Observed from Skylab</u>
1975, submitted to Solar Physics.

45 Vaiana, G.S., A.S. Krieger, J.K. Silk, A.F. Timothy, L. van Speybroeck, M.V. Zombeck
<u>The AS&E X-ray Telescope Experiment on Skylab</u>
(in preparation)

Presentations

46 Vaiana, G.S., R.C. Chase, J.M. Davis, M. Gerassimenko, L. Golub, S. W. Kahler, A.S. Krieger, R. Petrasso, J.K. Silk, R. Simon, A.F. Timothy and D. Webb
<u>A view of the X-ray corona from Skylab</u>
1973, invited paper presented at Spec. Solar Phys. Div. Symp., Am. Phys. Soc./Am. Astronomical Mtg., Tucson

47 Krieger, A.S.
<u>Observations of coronal structures and the inferred coronal magnetic fields</u>
1974, presented at Seminar on Flare Related Magnetic Field High Altitude Obs., Boulder

48 Vaiana, G.S., R. Chase, J. Davis, M. Gerassimenko, L. Golub, S. Kahler, A. Krieger, R. Petrasso, J. Silk, R. Simon, A. Timothy and D. Webb
<u>Results from the X-ray spectrographic telescope</u>
1974, invited paper presented at 4th Solar Physics Div. Mtg. Am. Astro. Soc., Hawaii

49 Haggerty, R., R. Simon, L. Golub, J.K. Silk, A.F. Timothy, A.S. Krieger and G.S. Vaiana
<u>Soft X-ray Imaging on Photographic Film</u>
1974, presented at AAS Working Group on Photographic Materials, Rochester, N.Y.

50 Simon, R., R. Haggerty, L. Golub, A. Krieger, J. Silk, A.F. Timothy, G.S. Vaiana
<u>Response of Photographic Film to Soft X-ray Radiation</u>
1974, presented at AAS Working Group on Photographic Materials, Rochester, N.Y.

51 Petrasso, R.D., M. Gerassimenko, S. Kahler, A. Krieger, J. Silk, A.F. Timothy, G.S. Vaiana
<u>X-ray Observations of Active Region Development</u>
1974, presented at Intl. Conf. on X-rays in Space, Univ. of Calgary

52 Vaiana, G.S., R. Chase, J. Davis, M. Gerassimenko, L. Golub, S. Kahler, A. Krieger, R. Petrasso, J. Silk, R. Simon, A. Timothy, D. Webb
A review of the structure of X-ray corona and its role in solar-terrestrial relations
1974, invited paper, 55th AGU Mtg., Washington, D.C.

53 Vaiana, G.S., A. Krieger, R. Petrasso and J. Silk
The ASE X-ray telescope on Skylab
1974, invited paper at Optical Soc. of America Spring Mtg. Washington, D.C.

54 Vaiana, G.S. and A.S. Krieger
Observations of the X-ray corona with S-054 X-ray telescope
1974, invited paper at IAU Symp. #68, Buenos Aires

55 Kahler, S.W.
Thermal and non-thermal Interpretations of Flare X-ray Bursts
1974, invited paper at IAU-COSPAR Symp #68, Buenos Aires

56 Vaiana, G.S.
ATM X-ray telescope results
1974, invited paper at Special ATM Seminar of COSPAR Mtg., Sao Paulo, Brazil

57 Vaiana, G.S., A.S. Krieger, A.F. Timothy, and M. Zombeck
ATM Observations, X-ray Results
1974, presentation at IAU Colloquium #27, Cambridge, Mass.

58 Vaiana, G.S.
The X-ray Corona from Skylab
1975, presentation at the Discussion Mtg. on The Physics of the Solar Atmosphere of the Royal Society, London, 14-15 January.

Figure 1 Plot of the total number of frames exposed for each day of the Skylab missions and the number of internegs (shaded portions) produced for each day to July 1975.

Figure 2 X-ray images taken during five of the solar rotations observed during the mission. Each image is one rotation ahead of the image immediately above it, and adjacent images are separated by a quarter rotation. North is at the top of each image and West is to the left. The exposure time was 64 seconds, and the softest filter, No. 3, was used.

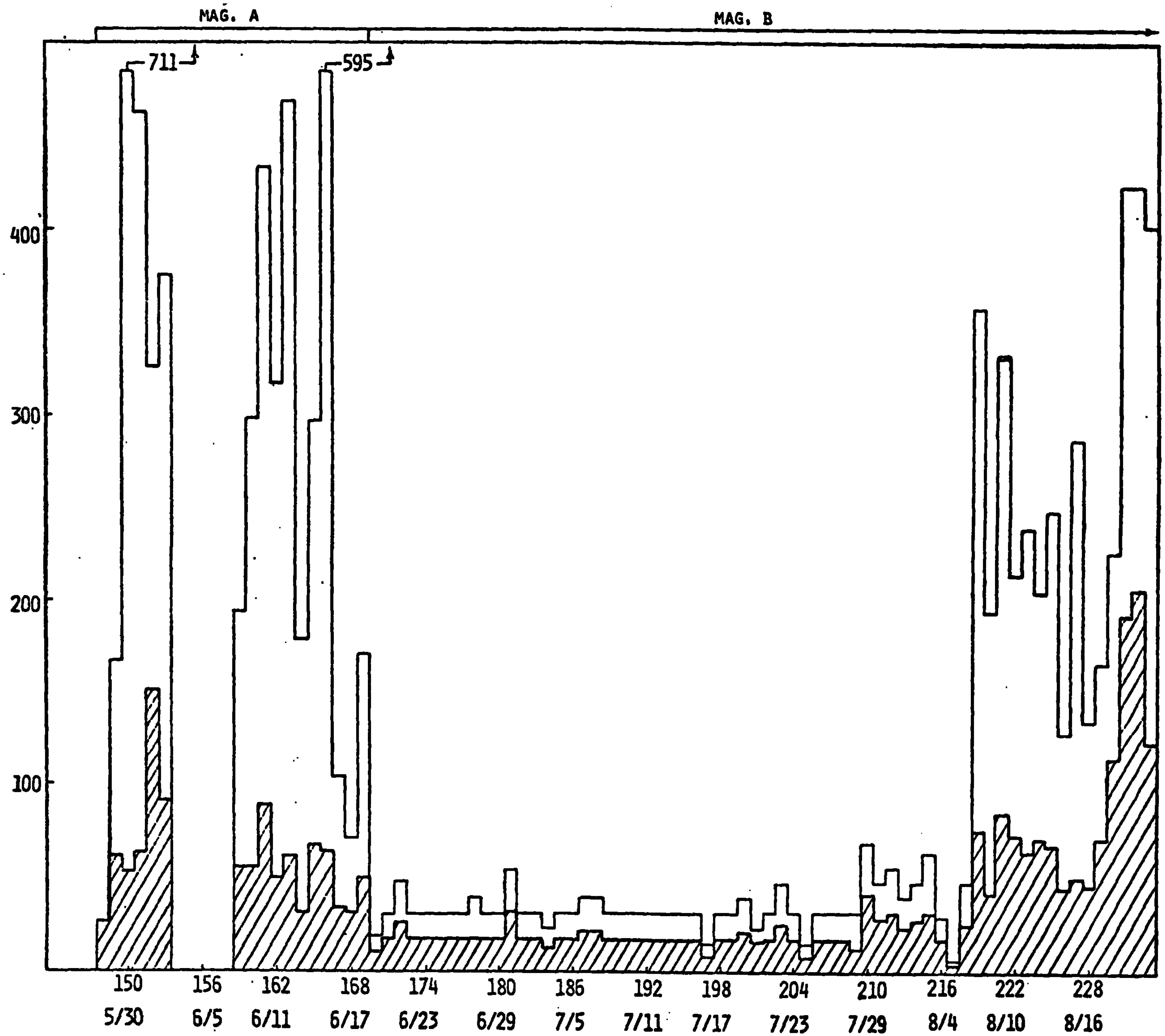
Figure 3 A three-day development of active region (NOAA 137) from 14 June to 17 June 1973. Both the X-ray images (hard filter, two exposure times) and Kitt Peak magnetograms are shown.

Figure 4 Active region NOAA 137 on 16 June 1973 with exposures through hard (upper row) and soft (lower row) filters, showing short-term structural and temperature variations.

Figure 5 Block diagram of data reduction and analysis procedure.

Figure 6 Example of the X-ray data reduction and analysis sequence. (a) The X-ray sun on August 29, 1973. North is up, East to the left. Filter 3, 16-second exposure. (b) The same as (a) except Filter 1 and 64-second exposure. (c) A contour map of the density for the image in (a). Isophotes are linear density increments. (d) A contour map of the density for the image in (b). Isophotes are linear density intervals. (e) and (f) Scatter plots for Filters 3 and 1, respectively.
(g) and (h) Contour maps of the energy per unit area per unit time E_i^o deposited in the focal plane for Filters 3 and 1,

respectively. The isophotes are logarithmic intervals. The maps are of the area outlined in (c) and (d).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MAG. B
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595
400
300
200
100
150
156
162
168
174
180
186
192
198
204
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222
228
5/30
6/5
6/11
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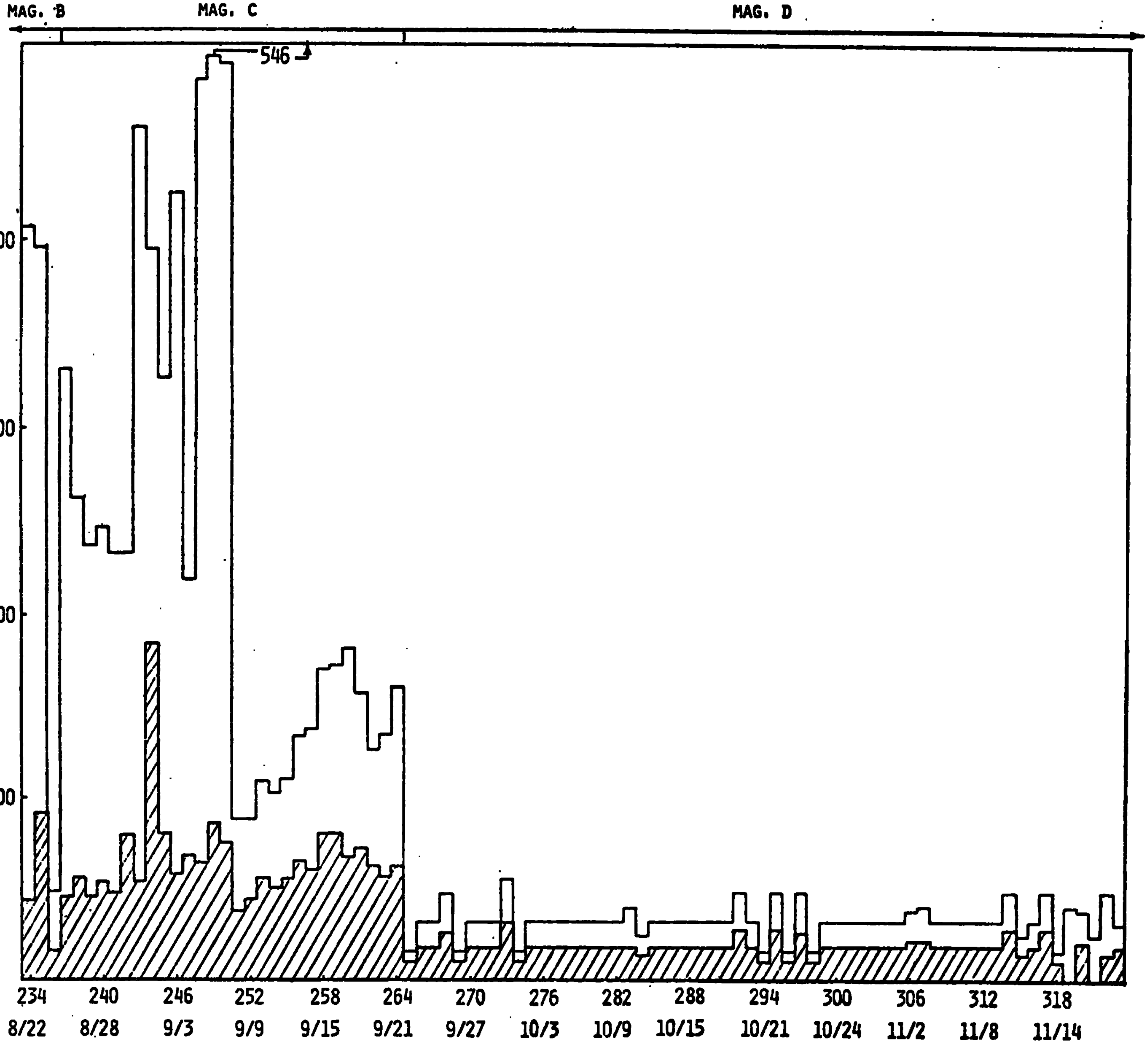
8/10
8/16

Figure 1a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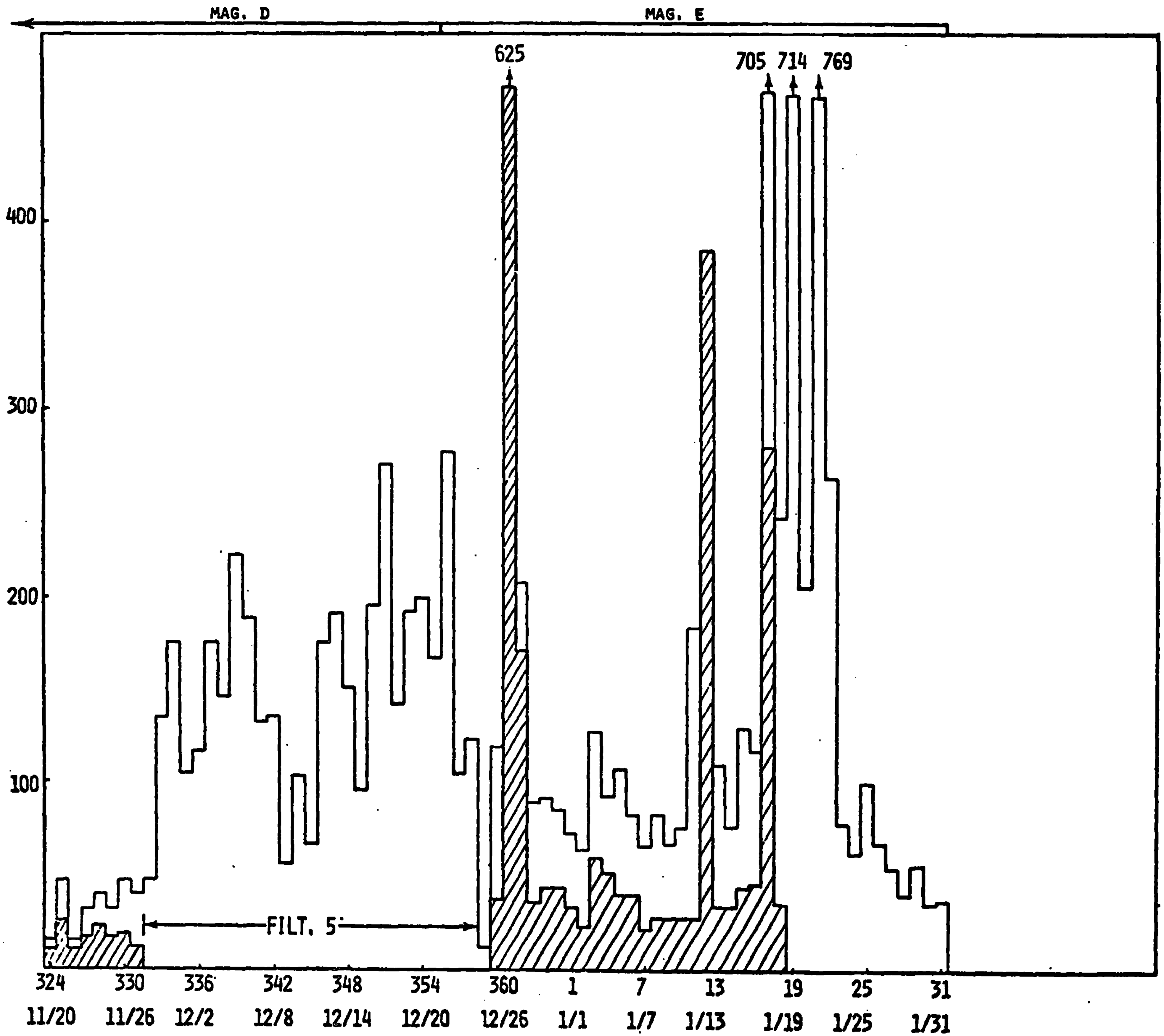
MAG. C
MAG. D
546
400
300
200
100
234 240 246 252 258 264 270 276 282 288 294 300 306 312 318
8/22 8/28 9/3 9/9 9/15 9/21 9/27 10/3 10/9 10/15 10/21 10/24 11/2 11/8 11/14

Figure 1b


MAG. D
MAG. E
625
705
714
769
400
300
200
100
FILT. 5
324
330
336
342
348
354
360
1
7
13
19
25
31
11/20
11/26
12/2
12/8
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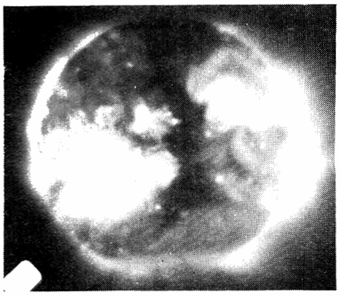
12/20
12/26
1/1
1/7
1/13
1/19
1/25
1/31

Figure 1c

1973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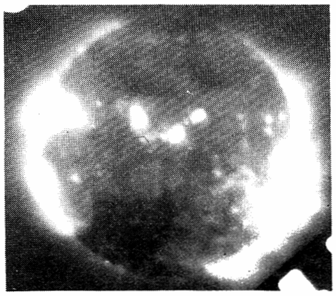
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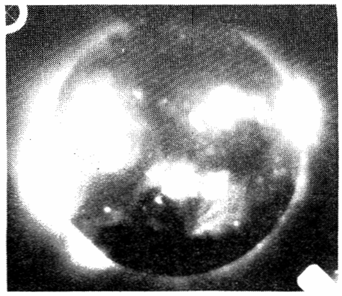
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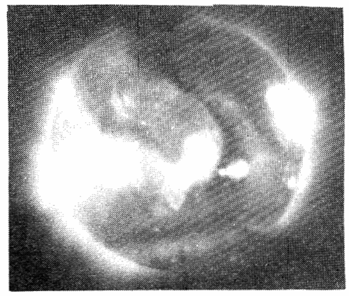
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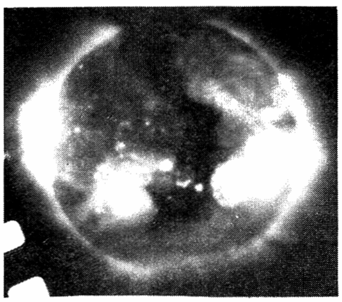
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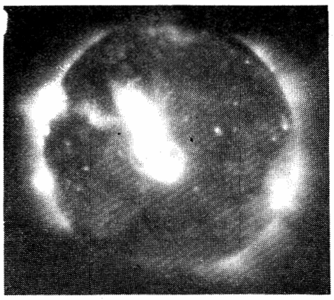
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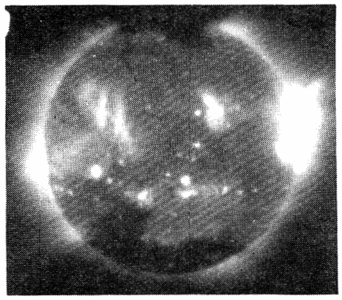
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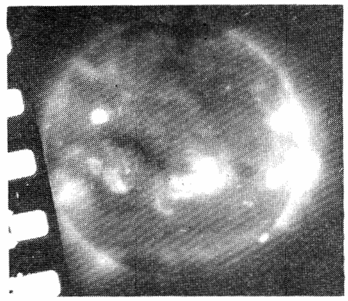
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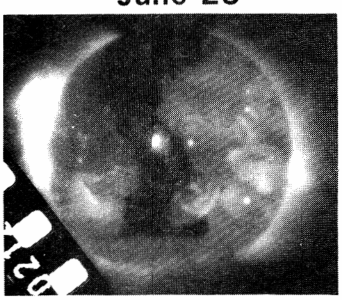
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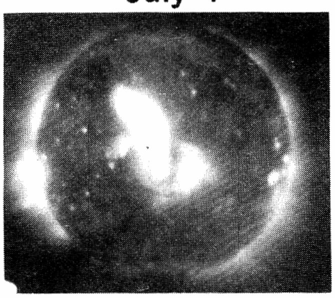
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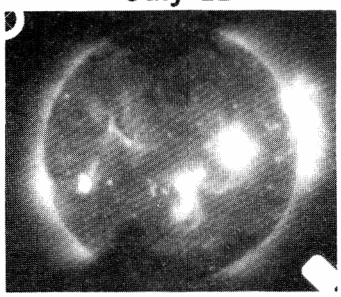
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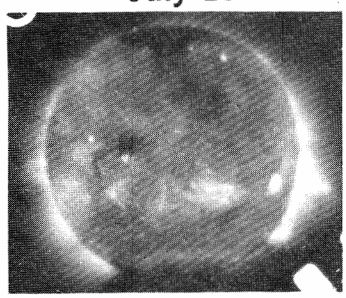
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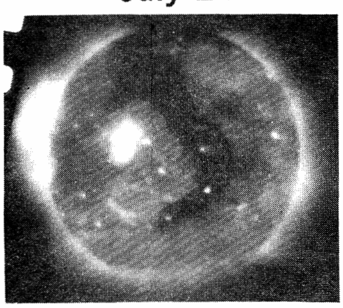
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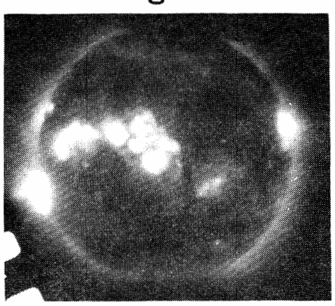
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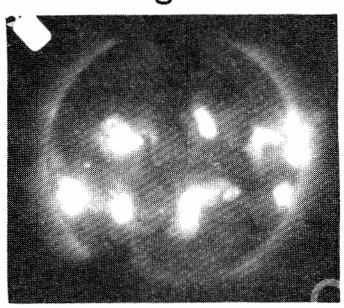
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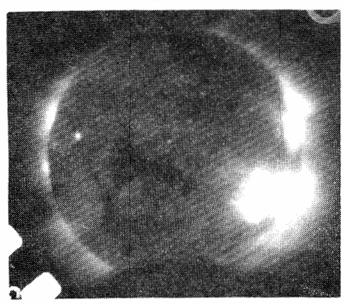
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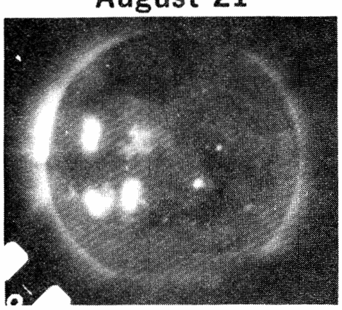
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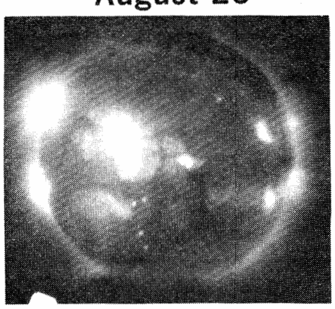
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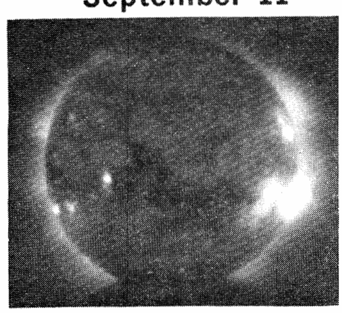
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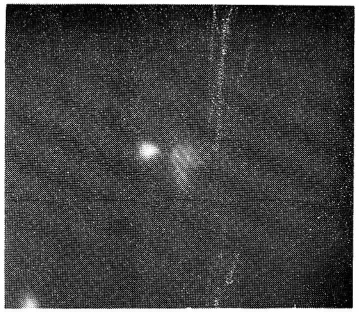

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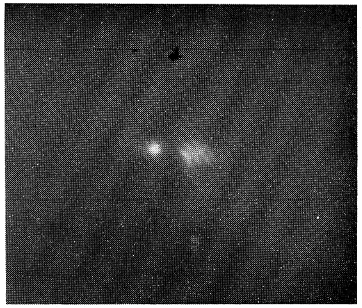

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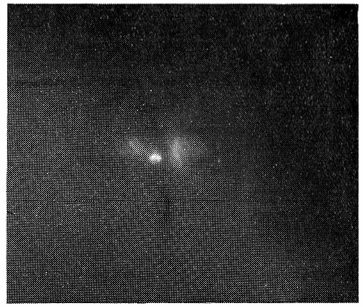

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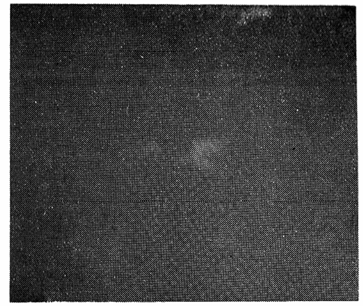

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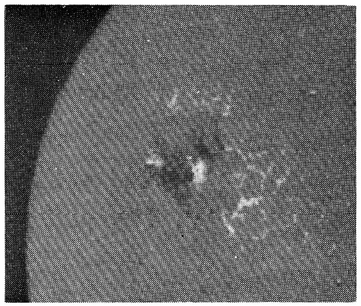

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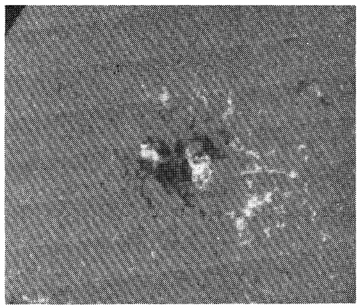

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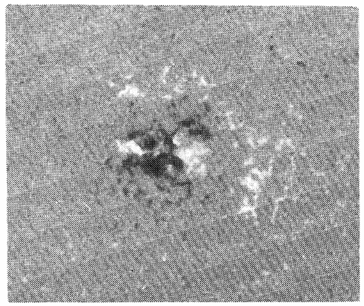

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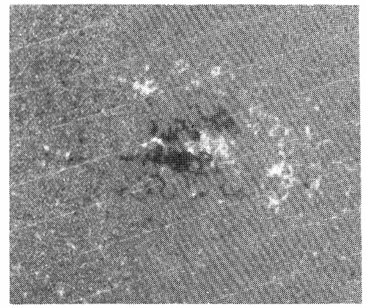

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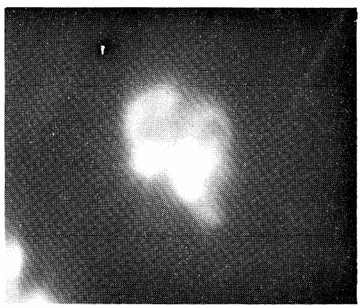

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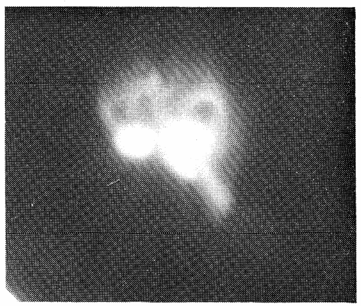

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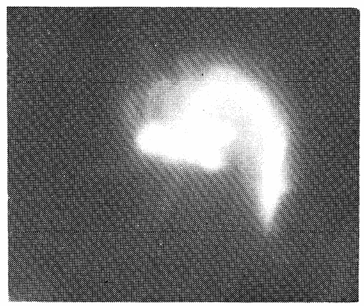

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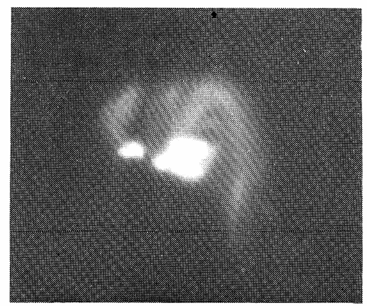

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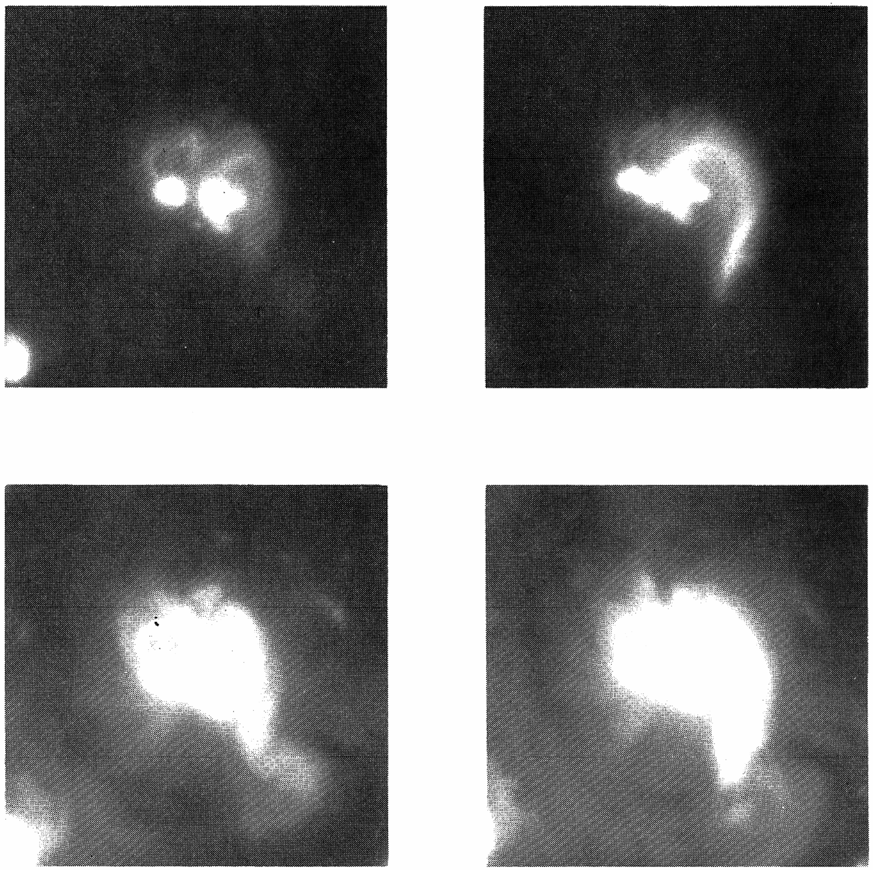

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SL-0068

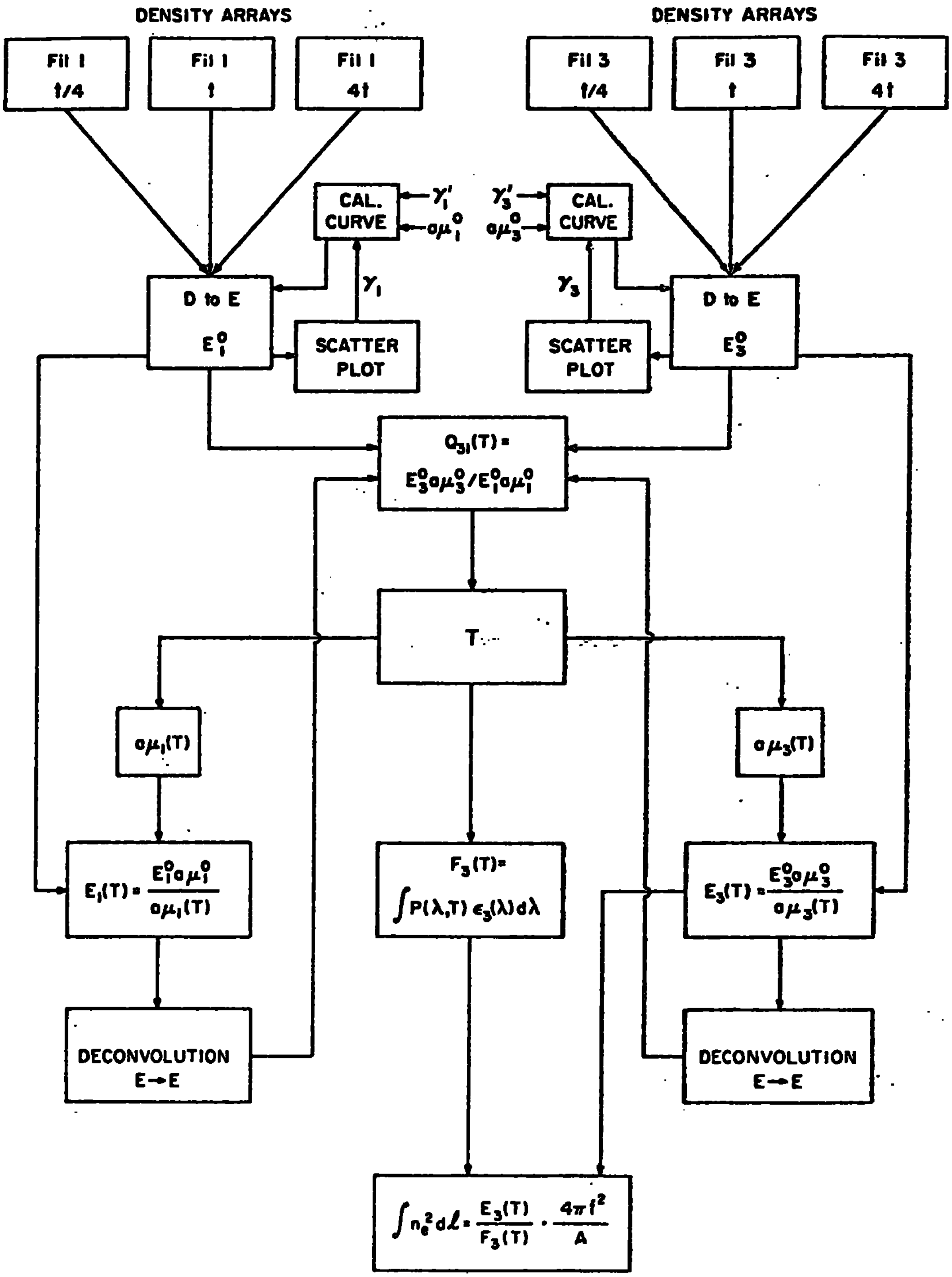
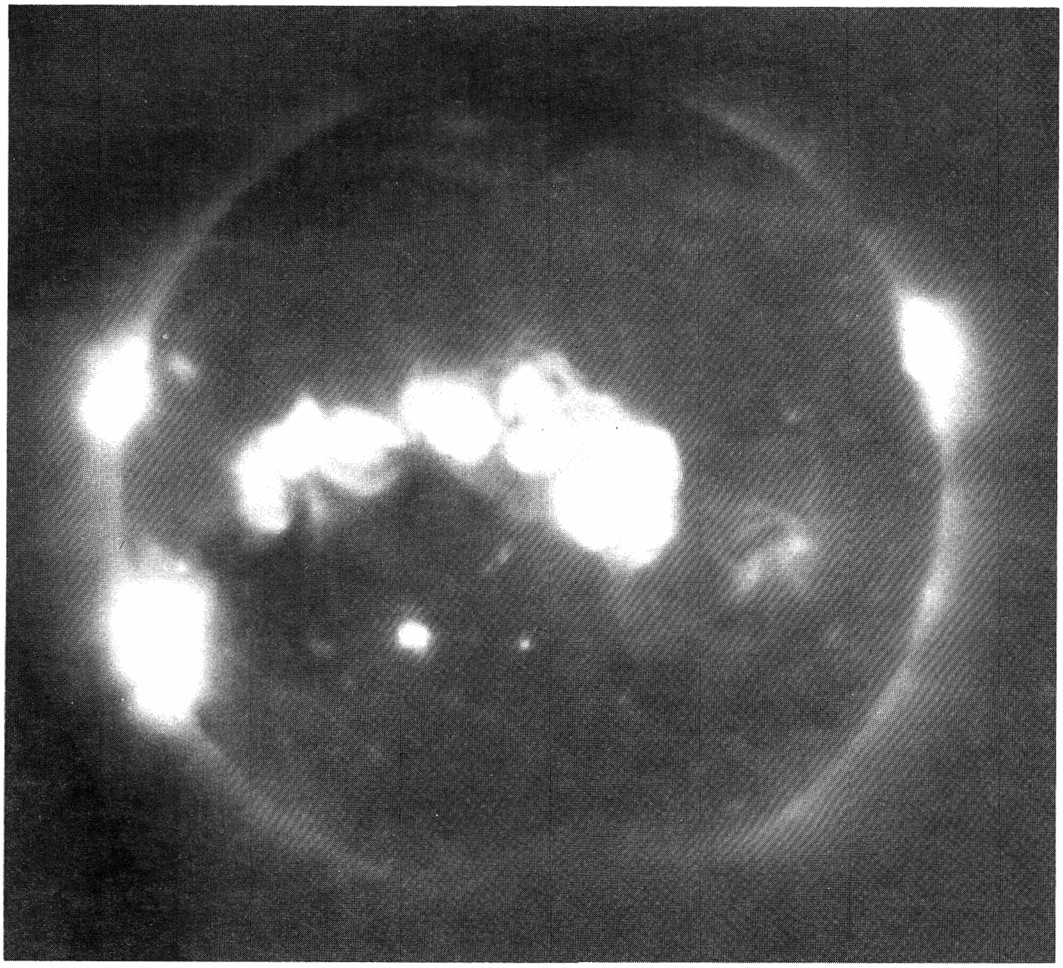

DENSITY ARRAYS
Fil 1 t/4
Fil 1 t
Fil 1 4t
DENSITY ARRAYS
Fil 3 t/4
Fil 3 t
Fil 3 4t
CAL. CURVE
CAL. CURVE
D to E E_1^0
D to E E_3^0
SCATTER PLOT
SCATTER PLOT
$Q_{31}(T) = E_3^0 a\mu_3^0 / E_1^0 a\mu_1^0$
T
$a\mu_1(T)$
$a\mu_3(T)$
$E_1(T) = \frac{E_1^0 a\mu_1^0}{a\mu_1(T)}$
$F_3(T) = \int P(\lambda,T)\,\epsilon_3(\lambda)\,d\lambda$
$E_3(T) = \frac{E_3^0 a\mu_3^0}{a\mu_3(T)}$
DECONVOLUTION E→E
DECONVOLUTION E→E
$\int n_e^2 d\ell = \frac{E_3(T)}{F_3(T)} \cdot \frac{4\pi f^2}{A}$

Figure 5



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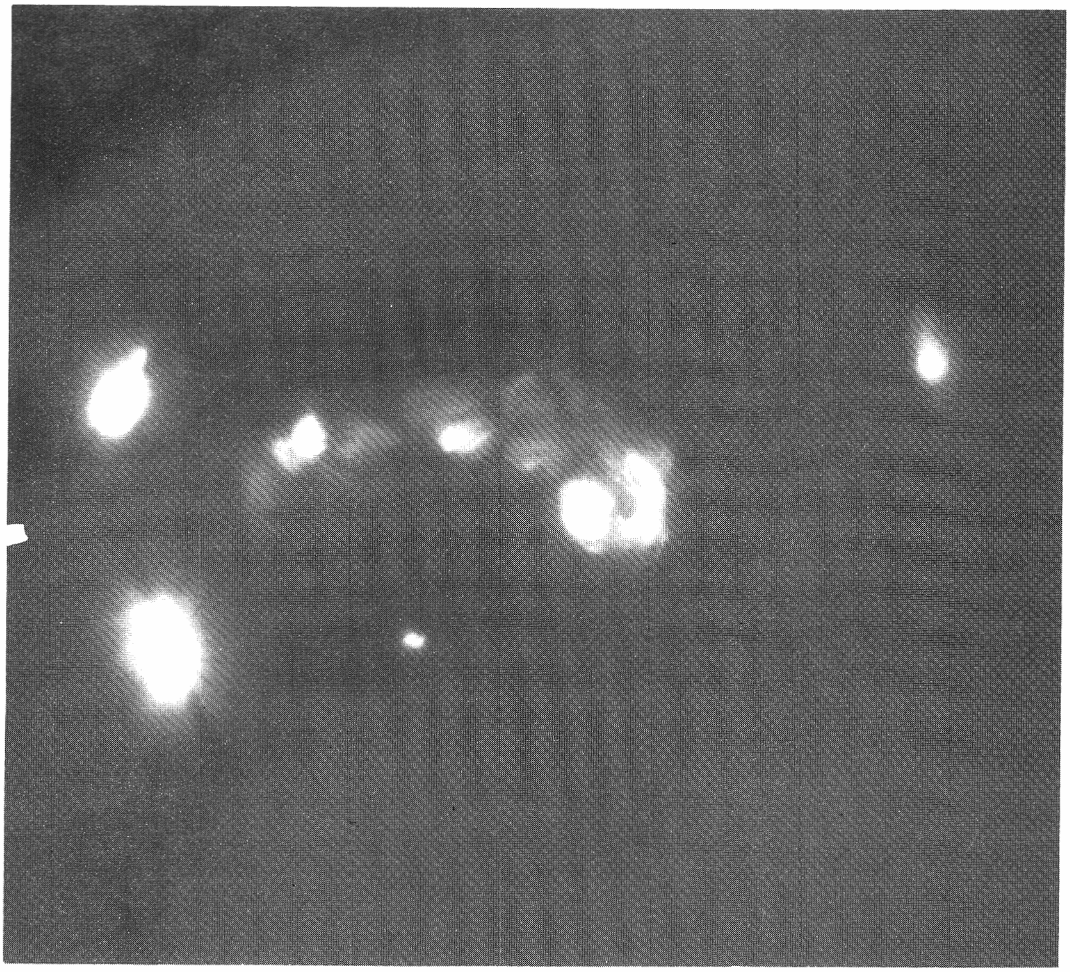

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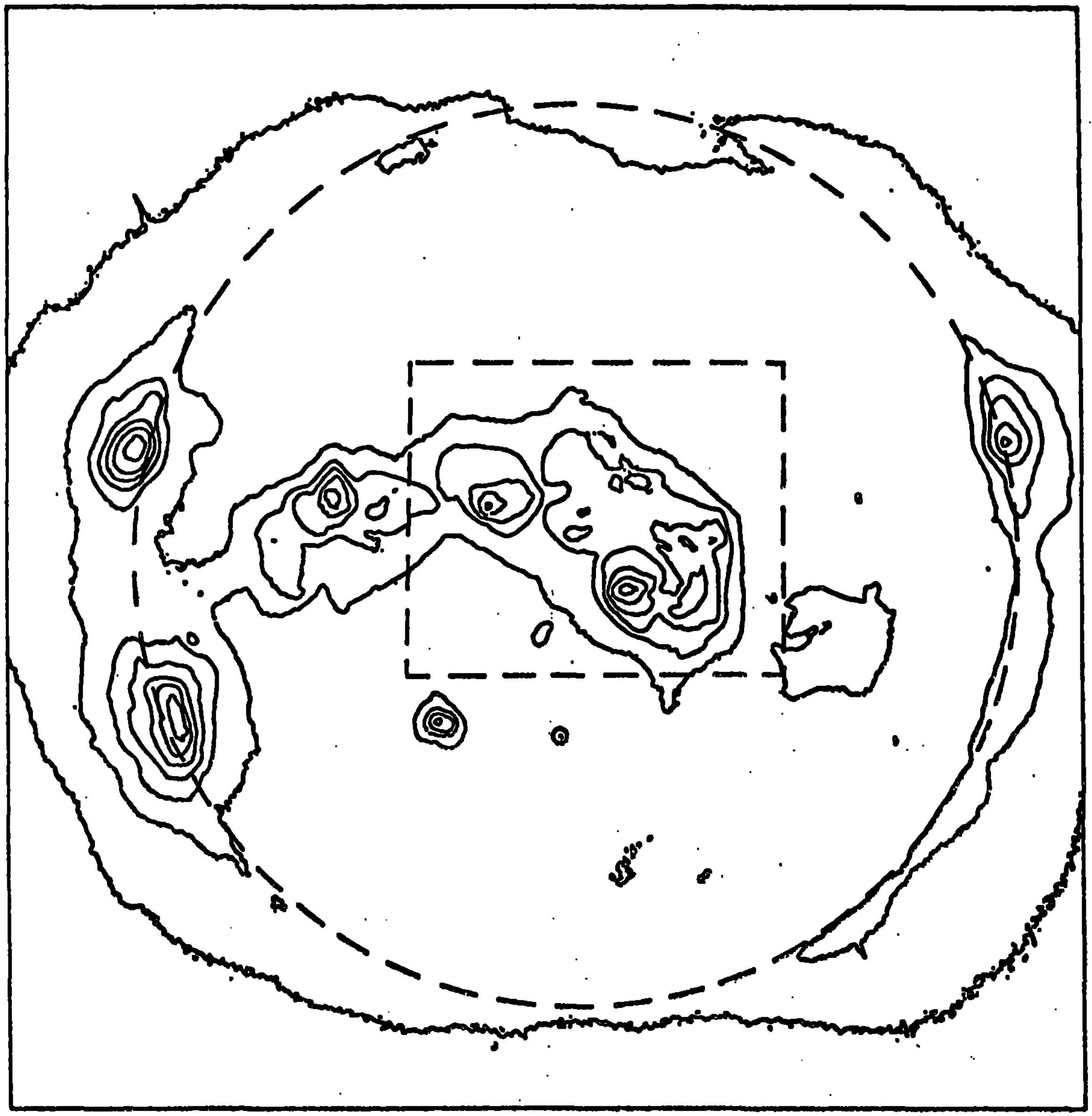


Figure 6c

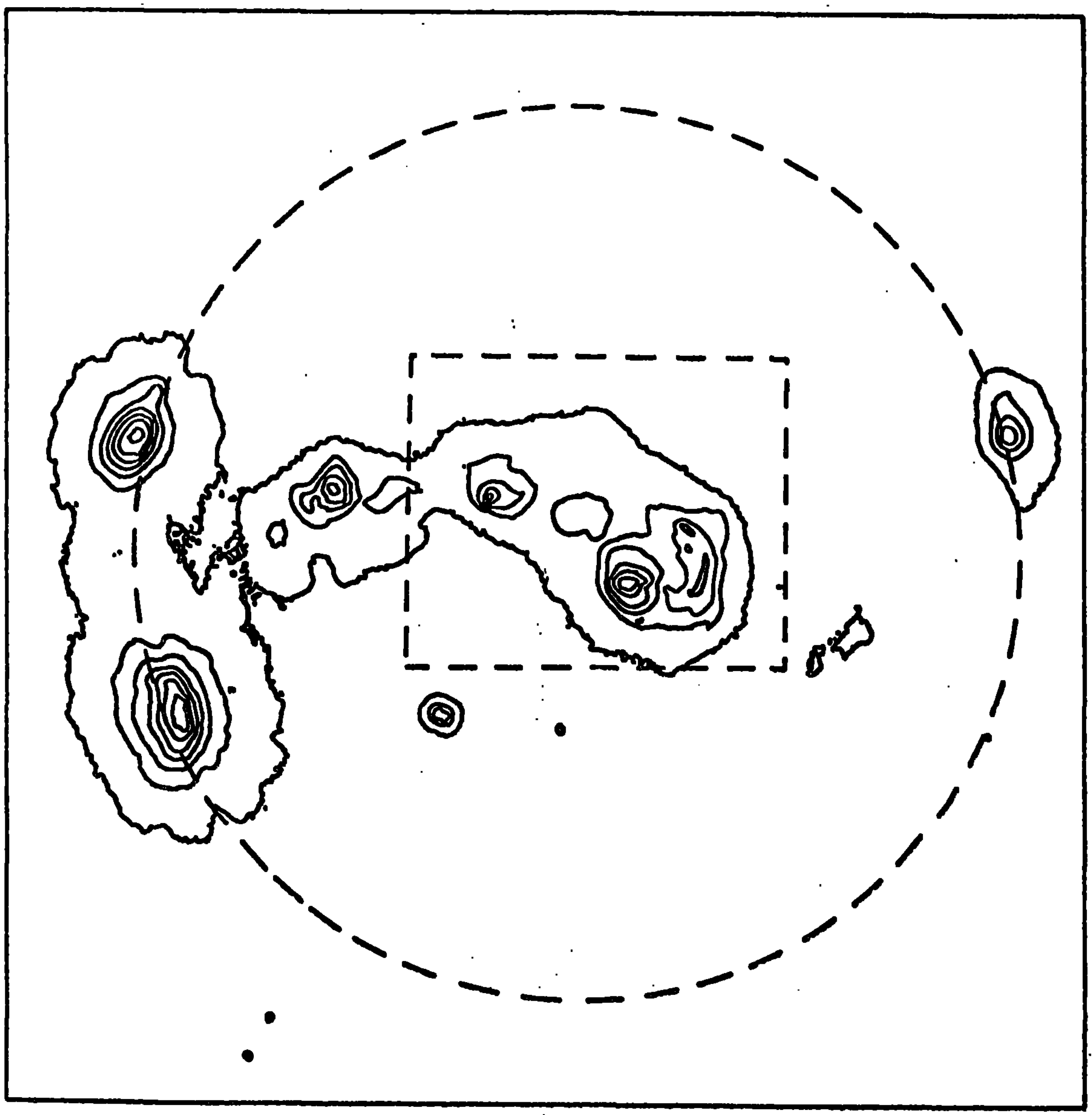
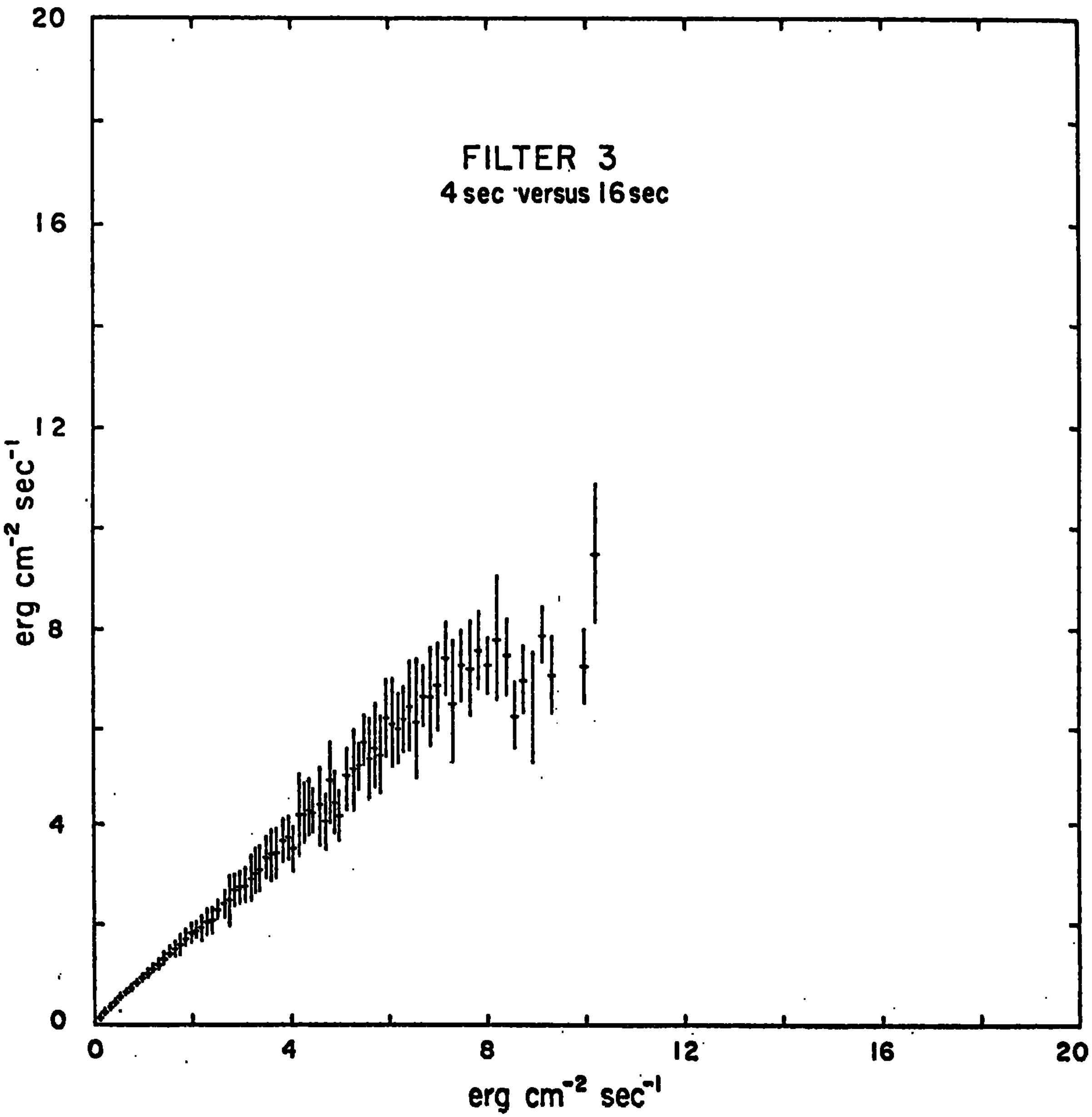


Figure 6d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4 sec versus 16 sec
20
16
12
8
4
0
0
4
8
12
16
20
erg cm^{-2} sec^{-1}
erg cm^{-2} sec^{-1}

Figure 6e

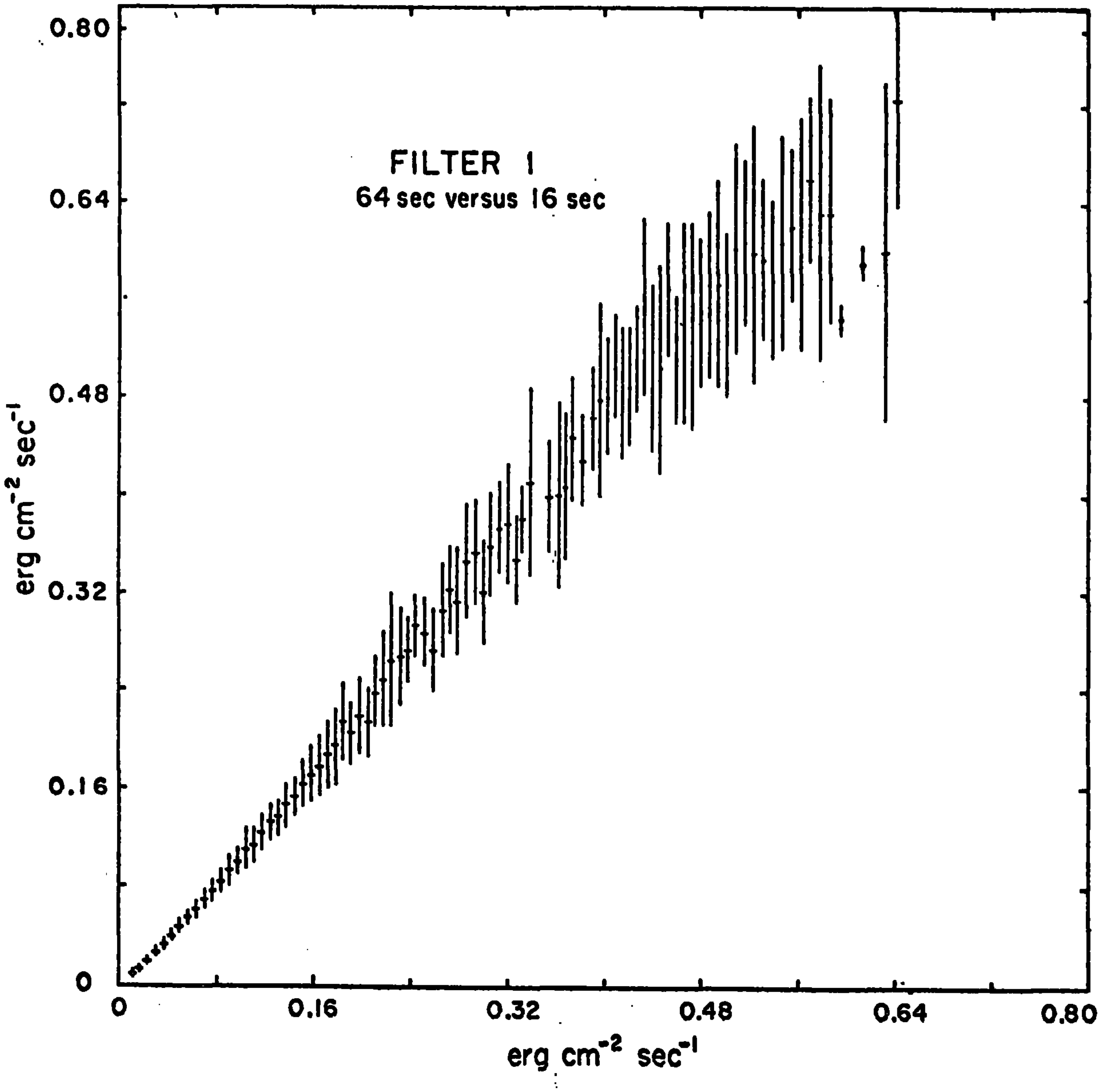
FILTER 1
64 sec versus 16 sec
erg cm^{-2} sec^{-1}
0.80
0.64
0.48
0.32
0.16
0
0
0.16
0.32
0.48
0.64
0.80
erg cm^{-2} sec^{-1}

Figure 6f

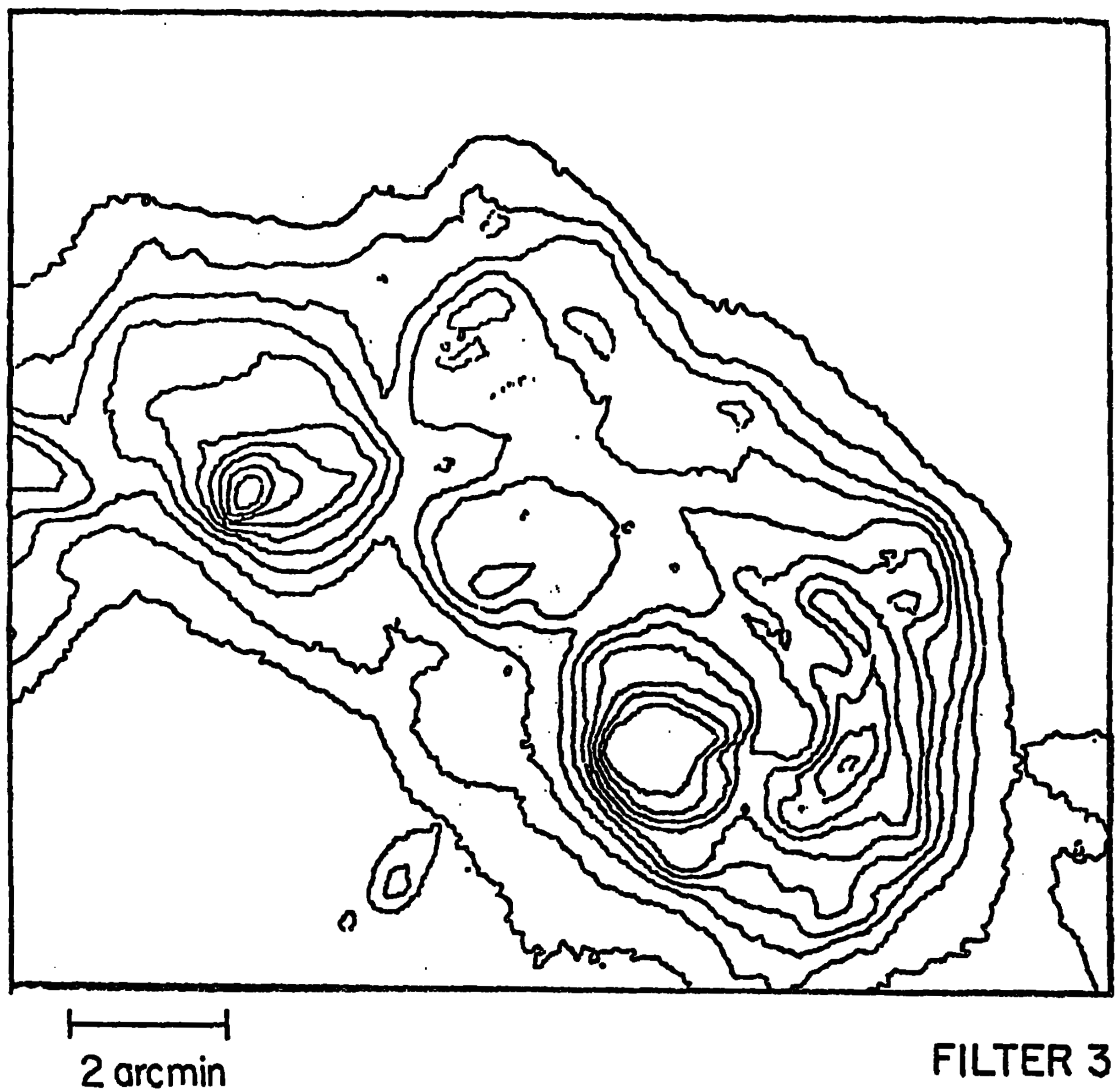

Figure 6g

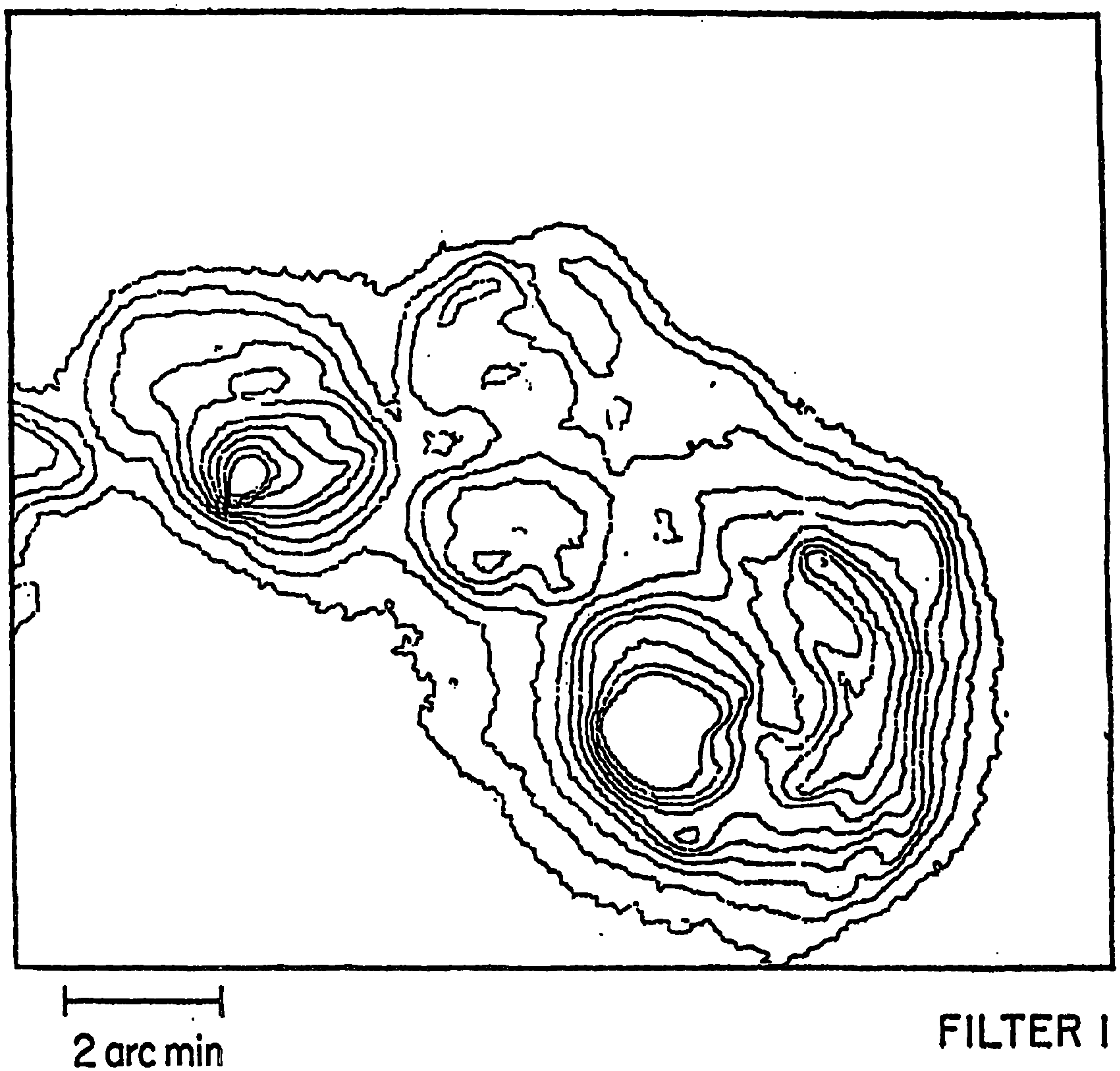

Figure 6h

SKYLAB APOLLO TELESCOPE MOUNT

S055

EUV SPECTROHELIOMETER

Harvard University
Harvard College Observatory
Cambridge, Massachusetts

TABLE OF CONTENTS

1.0 INTRODUCTION

This report covering the month of June, 1975, describes activities at HCO under Contract NAS5-3949. Being the last report for Fiscal Year 1975, we are devoting the bulk of the report to a summary of scientific results obtained to date from the S055 Spectroheliometer data.

The production of final data at MSFC and JSC was completed in June, and all the S055 final data tapes and microfiche have been received at HCO. The BBRC support group at JSC has returned home and the office has been closed. The ATM mission log, prepared by BBRC under subcontract, has been shipped to ATM PI's and the subcontract has been terminated as of June 30.

The H-Alpha Atlas is 80% complete, and is being shipped to ATM PI's. The data guides and handbooks that will accompany the data submittal to the National Space Science Data Center are 75% complete. The S055 Mission Log is 40% complete.

In short, the bulk of the data reduction, engineering support, and organization of the data bank is complete, although progress on those tasks which still remain will continue to be reported. The following sections of this report describe preliminary results of the scientific data analysis.

2.0 SUMMARY OF PRELIMINARY SCIENTIFIC RESULTS.

The Harvard College Observatory Experiment on ATM was an outstanding scientific success. It has provided a wealth of scientific observations on diverse solar phenomena and features, observations which provide a data base that will be exploited for many years. In the following paragraphs we briefly summarize some of the results that have already been obtained from these observations, with some of the publications where the results were reported. A bibliography is included at the end.

3.0 TIME VARIATIONS IN EUV EMISSION LINES.

Among the most important observations obtained by the experiment is the discovery (14) of EUV brightness changes that may be associated with mechanical waves which heat the corona. Detection of the phenomena responsible for heating the corona has eluded solar astronomers for many years. The most accepted theory is that the corona is heated by upward propagating mechanical waves which are generated in lower atmospheric layers. Since oscillatory motions with a 300 second period have been observed in the photosphere, one might expect that there might be waves with a 300 second period moving upward through the chromosphere, transition layer, and corona. One also might expect that waves moving through the transition layer and corona would produce EUV brightenings that could be detected. The HCO experiment found evidence for brightenings with a 300 second period in the chromosphere, but no evidence for periodic brightenings in higher layers. However, aperiodic brightenings with an average duration of 70 seconds were found in lines formed in the chromosphere, transition region and corona. If further analyses confirm, as the preliminary results suggest, that the brightenings are associated with upward propagating phenomena, then ATM may well have detected for the first time the waves heating the corona.

4.0 STRUCTURE OF THE QUIET ATMOSPHERE.

The problem of the structure of the quiet solar atmosphere is closely related to the heating problem. In order to develop reliable theories for the outer solar atmosphere, it is essential to understand the mass and energy balance in each layer, how much mass and energy flows into each layer from adjacent layers, and how much flows out. What is the role of the magnetic field which controls the flow of energy by conduction (along field lines) and the solar wind, which can be an important source of the mass and energy loss in magnetically open regions? What is the difference in physical conditions in the chromospheric network and intra-network areas? How does the network extend upward into the transition layer and corona? How much EUV radiation is emitted by spicules?

One of the earliest ATM results was the discovery that although the chromospheric network is clearly visible in lines formed in the chromosphere and transition region, it is only marginally visible in coronal lines (9, 32, 35). Furthermore, the maximum contrast between the network and intra-network areas occurs in lines formed at temperatures near 10^5 K, with lines formed at lower and higher temperatures exhibiting lower contrast. The interpretation of these data is well underway with preliminary results being reported in papers (6, 7, 9). Preliminary results of the analyses suggest that the corona in typical quiet areas is relatively homogeneous and extends downward to within about 8000 kilometers of the photosphere. The transition region in the network is on the average about a factor of 3 thicker than in intra-network areas. The model for the network indicates that, in contrast to earlier spherically symmetric models, energy losses by conduction no longer dominate the temperature structure in the transition layer, since radiative losses are of equal importance. Spicules apparently emit significant amounts of EUV radiation, about 10% to 20% of the total EUV emission from quiet areas of the sun (7). Determination of the amount of EVU emission from spicules will permit for the first time the development of models for the transition sheath which separates cool Hα emitting spicular material from the hot surrounding corona.

Mariska, Reeves and Withbroe are continuing their work on the development of models for the transition layer and corona, while Vernazza and Avrett continue their work on chromosphere models.

5.0 CORONAL HOLES.

Another important discovery made with ATM observations, is the direct measurement of the increased thickness of the transition layer in coronal holes (as compared to the thickness in quiet regions). This was first noted in the NRL S082A data by Sheeley and subsequently confirmed with the HCO data (26). The possibility that the transition layer is thicker in coronal holes than in normal quiet areas was first suggested by analyses of data from HCO OSO experiments, but the spatial resolution of the OSO data did not permit this possibility to be firmly established. The confirmation of this hypothesis by ATM is important because the thickness of the transition layer in coronal holes appears to be related to the fact that coronal holes are apparently strong sources of high speed coronal wind streams. (The latter result has been demonstrated in analyses of data from other ATM experiments, especially S054.) Because a substantial amount of coronal energy is lost in the solar wind, the amount of energy conducted from the corona to the transition region is lower in a coronal hole than in a normal quiet area, thereby reducing the temperature gradient and thickness of the transition region. Analyses of ATM EUV data also suggest that there are differences between coronal holes and normal quiet regions in the brightness of the chromospheric network (9, 26).

A primary objective of the HCO experiment team and their collaborators is the development of empirical, inhomogeneous, three dimensional models for the chromosphere, transition region and corona, for both quiet regions and coronal holes. Through such models we hope to understand how and why a coronal hole differs from a normal quiet region. Work on the development of such models continues.

6.0 MACROSPICULES

Another discovery made with the ATM EUV experiments is the macrospicule. These features, which appear to be jets of chromospheric material that shoot as high as 1 arc minute above the limb in polar coronal holes, have the characteristics of small surges or giant spicules. They were independently discovered in the NRL S082Å and HCO S052 data. The data from the two experiments is complementary. Because of its large field of view, the NRL experiment obtained statistics on many macrospicules, however, primarily only in one line, He IIλ304. The HCO experiment had a smaller field of view and was pointed at polar regions only infrequently, hence obtained observations of only a few macrospicules. However, because of the sensitivity and photometric precision of a photoelectric experiment and its capability to detect EUV emission from macrospicules in several lines, the HCO data are particularly useful for constructing models for individual macrospicules. These models (74) have yielded estimates for the mass of macrospicules as well as for the energy required to produce them. Because of the large amount of energy required to generate macrospicules, it appears that they are most likely produced by a mechanism that utilizes energy stored in the chromospheric magnetic field.

7.0 CORONAL LOOPS.

Among the most interesting observations obtained by the EUV experiments on ATM are those of coronal loops. Before ATM it was generally believed that the coronal layers over active regions consisted primarily of high-temperature material ($T>10^6$ K) except for cool material in filaments associated with the regions. The ATM observations show that the space above most active regions is filled with coronal loops containing material with temperatures ranging from 10^4 to a few million degrees K. Generally the loops with the smallest cross-sections contain material with temperatures between 10^5 and 10^6 K while the hotter loops are more diffuse and have broader cross-sections. Many, if not all, cool loops (temperatures less that 10^6) appear to be unstable, that is, emission from the loop undergoes significant changes in times of the order of a few minutes. The hotter loops (temperatures greater than 10^6 K) appear to be more stable. Many cool loops appear to be generated by material that is injected at the foot points of the loops. Others may well be caused by the condensation and cooling of hotter coronal material that falls back into the chromosphere at either end of the loops. The problem of the stability and configuration of coronal loops is under intensive investigation by Foukal, Levine, Withbroe and others.

Because coronal loops trace out the configuration of the coronal magnetic field, comparisons of EUV loop configurations with magnetic field configurations computed from measurements of the photospheric field are being made in order to develop information about the existence of coronal electric currents.

Another area of investigation is the evolution of active regions. Studies of evolutionary trends are underway by Foukal, Levine and others. Of particular interest are evolutionary changes in the coronal structure as observed in EUV lines and the magnetic field configuration computed from photospheric magnetograms.

Results of work on coronal loops have been reported in a number of papers (4, 23, 62).

8.0 SUNSPOTS.

Another major surprise provided by ATM was the discovery that the intensities of EUV lines formed in the transition layer (2×10^5 K < T <10^6 K) are extremely bright over sunspots (23, 65, 82). The reason for this appears to be that sunspots are often the footpoints for one or more coronal loops that have very thick transition layers (that is, the temperature gradient in the transition layer over the sunspot is very shallow). Because the transition layer is so thick, lines formed there are very intense. Models of these features have been derived which explain the appearance of the EUV emission over sunspots when viewed near sun center and at the limb (where the vertical extent of the EUV emission can be measured directly (65, 82).

Studies are also underway to determine if it is possible to detect umbral flashes in EUV lines. Preliminary results suggest that the Harvard experiment may have successfully observed phenomena that may be related to umbral flashes observed from the ground.

9.0 FLARES.

Preliminary analyses of flare data (29) from the HCO experiment indicate that the impulsive rise in EUV emission occurs essentially simultaneously at temperatures from

2×10^4 K to 2×10^6 K, at least to within the 5.5 second time resolution of the experiment. The rise time of impulsive emission is rapid, often with e-folding times shorter than 5.5 seconds. A number of small flares have been observed to occur at the foot-points of coronal loops (47, 48). These flares often eject chromospheric and transition region material up into the loops. EUV spectra of flares were also obtained and are being used to determine temperatures and densities in flares (29). Harvard EUV flare observations are being compared by Donnelly to measurements of sudden frequency deviations obtained using ground-based instrumentation.

10. EUV BRIGHT POINTS.

EUV bright points have been observed in all locations on the disk including coronal holes (35, 94). Many of these features appear to be associated with bipolar magnetic regions. Among the most interesting phenomena discovered by ATM are the bright point flares where the EUV emission from a bright point increases by an order of magnitude in a few minutes or less. In one case a bright point flare has been observed to flare initially in lines formed in the transition layer. For a large fraction of flaring events a bright point several thousand kilometers away has been seen to flare simultaneously although no connecting loop structures between these regions have been observed so far. Bright point flares may well be another example (like normal active region flares) of a region where energy stored in the magnetic field is converted rapidly into thermal energy. Work on bright points continues. The relationship between EUV and X-Ray bright points will be investigated in collaboration with members of the S054 experiment team.

11. PROMINENCES.

The HCO experiment acquired a rich supply of data on prominences and filaments, both quiescent and active. These data are under intensive study by Schmahl and collaborators (Orrall, Wagner and members of other ATM experiment teams). Some preliminary results of these investigations have been reported by Schmahl (10, 37, 68). Generally the EUV emission from a prominence or filament is similar to that from the quiet sun. However, the large opacity of the cool prominence material for wavelengths less than 912Å (caused by absorption in the H Lyman continuum) porduces important differences such as, for example, that prominences are often seen in absorption in coronal lines. It appears that typically the transition sheath separating cool prominence material from the hotter surrounding corona is less dense and thinner than the transition layer in quiet areas of the sun. The new EUV observations are being used to construct prominence models which include not only the cool regions visible with ground-based instrumentation, but also the transition sheath separating the cool priminence material from the hot surrounding coronal material in which the prominence is embedded. For the first time solar astronomers have access to prominence observations made with high spatial resolution in spectral lines and continua ranging form about 10^4 K to several million degrees K, which permit the construction of prominence models that are much more realistic than earlier models. The EUV data may also provide an opportunity to investigate how much material condenses out of the corona to form prominences. This is difficult to do with ground-based observations because it is impossible to observe the critical temperature range between 10^6 K and a few times 10^4 K, as can be done in the EUV.

12. DIAGNOSTIC TECHNIQUES.

Diagnostic techniques for obtaining information from the ATM observations are also the subject of intensive investigation. One of the principal new diagnostic tools is the interactive computer driven Solar Image Display which is being used in a number of ways to analyze the data such as: (1) displaying simultaneously on video in different colors spectroheliograms made in different wavelengths or at different times, (2) changing the contrast or displayed intensity versus detector count rate to enhance or suppress different features, (3) and flicker techniques which permit rapid comparison of several spectroheliograms so that changes occuring between them can be easily detected. This system is proving to be a powerful tool for analyzing a wide variety of problems.

Work on the development of spectroscopic diagnostic techniques continues. Dupree, Foukal and Jordan are investigating the problem of using intensity ratios of lines from ions in the beryllium isolectronic sequence to determine densities (77). Withbroe (18) has developed a new method for analyzing EUV spectra to determine how material in the line of sight is distributed as a function of temperature.

This technique provides very useful information for the derivation of temperature-density models. Dupree and Mariska are studying the effects of different processes on the ionization equilibrium in coronal plasmas. Mariska, Avrett and Withbroe are investigating the application of Avrett's sophisticated computor program, which solves radiative transfer problems, to the problem of generating empirical models for spicules and macrospicules. Vernazza is developing techniques for analyzing mirror line scan data to obtain information on periodic and aperiodic brightenings observed in the EUV data. He is also working on methods for adding spectral scans and smoothing them by Fourier techniques.

13. TERRESTRIAL ATMOSPHERE.

The Harvard ATM experiment has also acquired a large quantity of data on the terrestrial atmosphere. During each spacecraft sunrise and sunset when the experiment was turned on it measured the absorption of EUV solar radiation by the Earth's atmosphere. Through comparison of measurements made at different wavelengths, it is possible to determine the variation with height in the atmosphere of atomic and molecular oxygen and molecular nitrogen and the exospheric temperature. Preliminary results of these investigations have been reported (42, 93). Timothy and collaborators are continuing this work.

14. BIBLIOGRAPHY

A. Publications

1975

1. Dupree, A.K.: "Ultraviolet Observations of Capella from Copernicus", Bulletin of the American Astronomical Society 7 (1975) 359 (abstract).

2. Foukal, P.V.: "The Pressure Balance and Currents in Active Region Loop Structures", Bulletin of the American Astronomical Society 7 (1975) 346 (abstract).

3. Foukal, P.V. and Jokipii, J.R.: "On the Rotation of Gas and Magnetic Fields at the Solar Photosphere", Astrophysical Journal Letters (1975), in press.

4. Foukal, P.V.: "The Temperature Structure and Pressure Balance of Magnetic Loops in Active Regions", Solar Physics (1975) in press.

5. Mariska, J.T. and Withbroe, G.L.: "Analysis of EUV Limb Brightening Observations from ATM I: Model for the Transition Layer and Corona", Solar Physics (1975), in press.

6. Mariska, J.T. and Withbroe, G.L.: "Analysis of EUV Limb Brightening Observations from ATM II: Influence of Spicules", to be submitted to Solar Physics (1975).

7. Mariska, J.T. and Withbroe, G.L.: "Extreme Ultraviolet Solar Limb Brightening Observations of Lithium-Like Ions", Bulletin of the American Astronomical Society 7 (1975) 354 (abstract).

8. Raghavan, N. and Withbroe, G.L.: "EUV Analysis of an Active Region", Solar Physics (1975) in press.

9. Reeves, E.M.; Vernazza, J.E.; and Withbroe, G.L.: "The Quiet Sun in the Extreme Ultraviolet", submitted to the Proceedings of the Royal Society London (1975).

10. Schmahl, E.J.: "Eruptive Prominences in the EUV: Observations with the Harvard Spectrometer on ATM", Bulletin of the American Astronomical Society 7 (1975) 348 (abstract).

11. Timothy, J.G.; Reeves, E.M.; Chambers, R.M.; d'Entremont, A.M.; and Lanham, N.W.: "A Sounding Rocket Spectroheliometer for Photometric Studies at Extreme Ultraviolet Wavelengths", Space Science Instrumentation 1 (1975) 17.

12. Timothy, J.G.: "Photon-Counting Detector Arrays Based on Microchannel Array Plates", Proceedings of the Symposium on Imaging Techniques in Astronomy, Space Research Institute, Utrecht, The Netherlands, April, 1975; in press.

Publications, Continued
1975

13. Timothy, J.G.: "The Relationship Between Coronal Bright Points and the Chromospheric Network", Bulletin of the American Astronomical Society _7_ (1975) 350 (abstract).

14. Vernazza, J.E.; Foukal, P.V.; Huber, M.C.E.; Noyes, R.W.; Reeves, E.M.; Schmahl, E.J.; Timothy, J.G.; and Withbroe, G.L.: "Time Variations in Extreme-Ultraviolet Emission Lines and the Problem of Coronal Heating", Astrophysical Journal Letters (1975), in press.

15. Vernazza, J.E.: "Time Variations in the EUV Line Emission from the Chromosphere and Corona", Bulletin of the American Astronomical Society _7_ (1975) 365 (abstract).

16. Withbroe, G.L.; Jaffe, D.T.; Foukal, P.V.; Huber, M.C.E.; Noyes, R.W.; Reeves, E.M.; Schmahl, E.J.; Timothy, J.G.; and Vernazza, J.E.: "EUV Transients Observed at the Solar Pole", submitted to the Astrophysical Journal (1975).

17. Withbroe, G.L. and Jaffe, D.: "Polar Transients Observed in the EUV", Bulletin of the American Astronomical Society _7_ (1975) 354 (abstract).

18. Withbroe, G.L.: "The Analysis of XUV Emission Lines", to be submitted to Solar Physics (1975).

Publications

1974

20. Dupree, A.K.; Foukal, P.V.; Huber, M.C.E.; Noyes, R.W.; Reeves, E.M.; Schmahl, E.J.; Timothy, J.G.; Vernazza, J.E.; and Withbroe, G.L.: "Extreme Ultraviolet Solar Spectra from Skylab-Apollo Telescope Mount", (abstract), Bulletin of the American Astronomical Society 6 (1974) 349.

21. Dupree, A.K.: "Ultraviolet Observations of Chromospheric Emission Lines in G Stars", (abstract), Bulletin of the American Astronomical Society 6 (1974) 446.

22. Fisher, R.R.; Foukal, P.V.; Huber, M.C.E.; Noyes, R.W.; Reeves, E.M.; Schmahl, E.J.; Timothy, J.G.; Vernazza, J.E.; and Withbroe, G.L.: "Surge Observations from ATM Skylab", Transactions, American Geophysical Union 55 (1974) 408 (abstract).

23. Foukal, P.V.; Huber, M.C.E.; Noyes, R.W.; Reeves, E.M.; Schmahl, E.J.; Timothy, J.G.; Vernazza, J.E.; and Withbroe, G.L.: "EUV Observations of Sunspots with the Harvard Spectrometer on ATM", The Astrophysical Journal Letters 193 (1974) L143-145.

24. Foukal, P.V.: "A Measurement of Electron Temperature in the Orion Nebula from the Intensity Ratio of Forbidden Transitions in [S III]", Publications of the Astronomical Society of the Pacific, in press.

25. Huber, M.C.E.; Reeves, E.M.; and Timothy, J.G.: "Photometric Calibration of an Extreme Ultraviolet Spectroheliometer for the Skylab Mission", Space Optics (Proceedings of the Ninth International Congress of the International Commission of Optics), National Academy of Sciences, Washington, D.C. (1974) 33-54.

26. Huber, M.C.E.; Foukal, P.V.; Noyes, R.W.; Reeves, E.M.; Schmahl, E.J.; Timothy, J.G.; Vernazza, J.E.; and Withbroe, G.L.: "Extreme Ultraviolet Observations of Coronal Holes, Initial Results from Skylab", Astrophysical Journal Letters 194 (1974) L115-118.

27. Noyes, R.W.: "The Extreme Ultraviolet Spectrum of Solar Flares", High Energy Phenomena on the Sun Symposium Proceedings, Goddard Space Flight Center (1974) 231-241.

28. Noyes, R.W.: "The Extreme Ultraviolet Spectrum of Sunspots", (abstract), Bulletin of the American Astronomical Society 6 (1974) 428.

Publications, Continued
1974

29. Noyes, R.W.; Foukal, P.V.; Huber, M.C.E.; Reeves, E.M.; Timothy, J.G.: Vernazza, J.E.; and Withbroe, G.L.: "EUV Observations of the Active Sun from the Harvard Experiment on ATM", submitted to Proceedings of IAU Symposium No. 68.

30. Noyes, R.W.; Foukal, P.V.; Huber, M.C.E.; Reeves, E.M.; Schmahl, E.J.; Timothy, J.G.; Vernazza, J.E.; and Withbroe, G.L.: "ATM Observations of Solar Flares in the Extreme Ultraviolet", Transactions, The American Geophysical Union 55 (1974) 408 (abstract).

31. Reeves, E.M.; Fisher, R.R.; Foukal, P.V.; Huber, M.C.E.; Noyes, R.W.; Schmahl, E.J.; Timothy, J.G.; Vernazza, J.E.; and Withbroe, G.L.: "EUV Observations of Coronal Holes with the Harvard ATM Experiment", Transactions, American Geophysical Union 55 (abstract) (1974) 408.

32. Reeves, E.M.; Foukal, P.V.; Huber, M.C.E.; Noyes, R.W.; Schmahl, E.J.; Timothy, J.G.: Vernazza, J.E.: and Withbroe, G.L.: "Observations of the Chromospheric Network: Initial Results from the Apollo Telescope Mount", The Astrophysical Journal Letters 188 (1974) L27-29.

33. Reeves, E.M.; Foukal, P.V.; Huber, M.C.E.; Noyes, R.W.; Schmahl, E.J.; Timothy, J.G.; Vernazza, J.E.; and Withbroe, G.L.: "Solar EUV Photoelectric Observations from Skylab", Coronal Disturbances (1974) 497-500.

34. Reeves, E.M.; Timothy, J.G.; and Huber, M.C.E.: "The Photoelectric Spectroheliometer on ATM", Proceedings of S.P.I.E. Seminar-in-Depth on Instrumentation in Astronomy II, Tucson, Arizona, 4-6 March, 1974, Proceedings of S.P.I.E. 44 (1974) 159.

35. Reeves, E.M.; Timothy, J.G.; Foukal, P.V.; Huber, M.C.E.; Noyes, R.W.; Schmahl, E.J.; Vernazza, J.E.; and Withbroe, G.L.: "Initial Results from the EUV Spectroheliometer on ATM", Proceedings of the AIAA/AGU Conference on the Scientific Experiments on Skylab, Huntsville, Alabama, in press (1974).

36. Reeves, E.M.: "Solar Physics Investigations on Skylab", (abstract), Bulletin of the American Astronomical Society 6 (1974) 225-226.

37. Schmahl, E.J.; Foukal, P.V.; Huber, M.C.E.; Noyes, R.W.; Reeves, E.M.; Timothy, J.G.; Vernazza, J.E.; and Withbroe, G.L.: "Solar Prominences in the Extreme Ultraviolet as Observed from the Apollo Telescope Mount", Solar Physics 39 (1974) 337-347.

Publications, Continued
1974

38. Timothy, J.G. and Reeves, E.M.: "Measurements of the Absolute Solar Flux at Extreme Ultraviolet Wavelengths from the ATM and ATM Calibration Rocket Spectroheliometers", (abstract), Transactions, American Geophysical Union 56 (1974) 1156.

39. Timothy, J.G. and Reeves, E.M.: "Preliminary Results from the Harvard ATM Calibration Rocket Program", Proceedings of the AIAA/AGU Conference on the Scientific Experiments on Skylab, Huntsville, Alabama, in press (1974).

40. Timothy, J.G.: "Preliminary Results with Saturable Micro-Channel Array Plates", Review of Scientific Instruments 45 (1974) 834.

41. Timothy, J.G. and Bybee, R.L.: "A One-Dimensional Photon-Counting Detector Array for Use at EUV and Soft X-Ray Wavelengths", submitted to Applied Optics, December, 1974.

42. Timothy, J.G.; Foukal, P.V.; Huber, M.C.E.; Noyes, R.W.; Reeves, E.M.; Schmahl, E.J.; Vernazza, J.E.; and Withbroe, G.L.: "Preliminary Results from ATM: Observations of the Earth's Upper Atmosphere", Transactions, American Geophysical Union 55 (1974) 372 (abstract).

43. Title, A.M.; Pope, T.P.; and Andelin, J.P., Jr.: "Drift in Interference Filters. Part 1", Applied Optics 13 (1974) 2675-2679.

44. Title, A.M.: "Drift in Interference Filters. 2: Radiation Effects", Applied Optics 13 (1974) 2680-2684.

45. Vernazza, J.E.; Avrett, E.H.; and Loeser, R.K.: "The Structure of the Solar Chromosphere II: The Photosphere Temperature Minimum", The Astrophysical Journal Supplement Series (1974), in press.

46. Vernazza, J.E.; Foukal, P.V.; Huber, M.C.E.; Noyes, R.W.: Reeves, E.M.; Schmahl, E.J.; Timothy, J.G.; and Withbroe, G.L.: "ATM Observations of the Time Dependent Intensity Fluctuations in the Extreme Ultraviolet", (abstract), Bulletin of the American Astronomical Society 6 (1974) 296.

47. Withbroe, G.L.; Foukal, P.V.; Huber, M.C.E.; Noyes, R.W.; Reeves, E.M.; Schmahl, E.J.; Timothy, J.G.; and Vernazza, J.E.: "Extreme Ultraviolet Solar Observations from the Harvard ATM Experiment", (abstract), Bulletin of the American Astronomical Society 6 (1974) 297.

48. Withbroe, G.L.; Fisher, R.R.; Foukal, P.V.; Huber, M.C.E.; Noyes, R.W.; Reeves, E.M.; Schmahl, E.J.; Timothy, J.G.; and Vernazza, J.E.: "Extreme Ultraviolet Observations Acquired by the Harvard ATM Instrument", Transactions, American Geophysical Union 55 (1974) 408 (abstract).

Publications
1973

49. Foukal, P.V.; Huber, M.C.E.; Noyes, R.W.; Reeves, E.M.; Schmahl, E.J.; Timothy, J.G.; Vernazza, J.E.; and Withbroe, G.L.: "A Study of the Active Region McMath 12417 with the Harvard ATM EUV Spectrometer", (abstract), Bulletin of the American Astronomical Society 5 (1973) 432.

50. Henze, W. and Dupree, A.K.: "Solar Rotation in the Chromosphere and Corona", Solar Physics 33 (1973) 425-429.

51. Huber, M.C.E.; Foukal, P.V.; Noyes, R.W.; Reeves, E.M.; Schmahl, E.J.; Timothy, J.G.; Vernazza, J.E.; and Withbroe, G.L.: "Observations of a Coronal Hole Boundary in the Extreme Ultraviolet", (abstract), Bulletin of the America Astronomical Society 5 (1973) 446.

52. Lapson, L.B. and Timothy, J.G.: "Use of MgF_2 and LiF Photocathodes in the Extreme Ultraviolet", Applied Optics 12 388-393.

53. Noyes, R.W.; Foukal, P.V.: Huber, M.C.E.; Reeves, E.M.; Schmahl, E.J.; Timothy, J.G.; Vernazza, J.E.; and Withbroe, G.L.: "ATM Observations of Solar Flares in the Extreme Ultraviolet", (abstract), Bulletin of the American Astronomical Society 5 (1973) 433.

54. Reeves, E.M.; Foukal, P.V.; Huber, M.C.E.; Noyes, R.W.; Schmahl, E.J.; Timothy, J.G.; Vernazza, J.E.; and Withbroe, G.L.: "Preliminary Solar Extreme Ultraviolet Observations from the ATM with the Harvard Instrument", (abstract), Bulletin of the American Astronomical Society 5 (1973) 419.

55. Reeves, E.M.; Noyes, R.W.; and Withbroe, G.L.: "Coordinated Observing Program", Skylab and the Sun, NASA, July, 1973, 36.

56. Reeves, E.M.; Noyes, R.W.; and Withbroe, G.L.: "The Scientific Instruments", Skylab and the Sun, NASA, July, 1973, 21-27.

57. Reeves, E.M.; Noyes, R.W.; and Withbroe, G.L.: "The Solar Joint-Observing Program", Skylab and the Sun, NASA, July, 1973, 30-34.

58. Schmahl, E.J.; Foukal, P.V.; Huber, M.C.E.; Noyes, R.W.; Reeves, E.M.; Vernazza, J.E.; and Withbroe, G.L.: "Solar Prominences in the Extreme Ultraviolet as Observed from the Apollo Telescope Mount", (abstract), Bulletin of the American Astronomical Society 5 (1973) 432.

59. Timothy, J.G.: "Use of Open-Structure Channel Electron Multipliers in Sounding Rocket Experiments", Review of Scientific Instruments 44 (1973) 207.

Publications
1972

60. Reeves, E.M.; Noyes, R.W.; and Withbroe, G.L.: "Observing Programs in Solar Physics During the 1973 ATM Skylab Program", Solar Physics 27 (1972) 251-270.

B. <u>Papers Presented</u>
1975

61. Gosling, J.T.; Bohlin, J.D.; Krieger, A.S.; Schmahl, E.J.; and Tandberg-Hanssen, E.: "A Review of Skylab/ATM Observations and Analyses of Coronal Transients", presented at the XVIII Annual COSPAR Meeting, Varna, Bulgaria, 29 May - 7 June, 1975.

62. Levine, R.H. and Withbroe, G.L.: "Physics of an Active Region Loop Event", presented at the 146th Meeting of the American Astronomical Society, San Diego, California, 1975; Bulletin of the American Astronomical Society, in press.

63. Levine, R.H. and Flagg, J.: "The Harvard Skylab Video Display System", presented at the Imaging in Astronomy Conference, Harvard University, 18 - 20 June, 1975.

64. Mariska, J.T. and Withbroe, G.L.: "Extreme Ultraviolet Solar Limb Brightening Observations", presented at the 146th Meeting of the American Astronomical Society, San Diego, California, 1975; Bulletin of the American Astronomical Society, in press.

65. Noyes, R.W.: "EUV Emission from Sunspots", presented at the Fifth Meeting of the Solar Physics Division of the American Astronomical Society, the University of Colorado, Boulder, Colorado, 20 January, 1975.

66. Reeves, E.M.: "Skylab EUV Observations", invited paper presented at the Discussion Meeting of the Royal Society (London): The Physics of the Solar Atmosphere, 14 January 1975.

67. Reeves, E.M.: "A Review of the Harvard Results from Skylab", presented at the special Colloquium Series on Skylab Experiments, the University of Maryland, College Park, Maryland, 19 March 1975.

68. Schmahl, E.J.: "Solar Prominences Observed in the EUV", presented at the joint Harvard, Kitt Peak, and Sacramento Peak annual Santa Fe Meeting, Santa Fe, New Mexico, May 1975.

69. Timothy, J.G.: "Evidence for Long-Term Variations in the Quiet Sun Emission at EUV Wavelengths", presented at the 146th Meeting of the American Astronomical Society, San Diego, California, 1975; Bulletin of the American Astronomical Society, in press.

Papers Presented, Continued
1975

70. Timothy, J.G.: "Photon-Counting Detector Arrays Based on Microchannel Array Plates", presented at the International Conference on Image Processing Techniques in Astronomy, Utrecht, The Netherlands, 24 - 27 March 1975; to be published in the Proceedings.

71. Timothy, J.G.: "The Use of Microchannel Array Plates in Photon-Counting Detection Systems", presented at the Topical Meeting on Imaging in Astronomy, Harvard University, Cambridge, Massachusetts, 18 - 20 June 1975.

72. Timothy, J.G.: "Instrumentation for Solar Spectrophotometry at Soft X-Ray Wavelengths", presented at the Symposium on Techniques of Solar and Cosmic X-Ray Spectroscopy, University College London, Mullard Space Science Laboratory, Surrey, England, 22 - 24 May 1975; Proceedings to be published in Space Science Instrumentation.

73. Vernazza, J.E.: "Time Variations in the EUV Intensity Observed from Skylab", presented at the joint Harvard, Kitt Peak, and Sacramento Peak annual Santa Fe Meeting, Santa Fe, New Mexico, May 1975.

74. Withbroe, G.L.: "Solar Structure in the Extreme Ultraviolet", presented at the 146th Meeting of the American Astronomical Society, San Diego, California, 1975; Bulletin of the American Astronomical Society, in press.

Papers Presented
1974

75. Dupree, A.K.: "Recent Results in Solar Ultraviolet Astronomy", invited paper presented at the Colloquium, Department of Physics, University of Tennessee, Knoxville, Tennessee, May 1974.

76. Dupree, A.K.; "Solar Astronomy from Space", invited paper presented at the Symposium on Space Astronomy, Wellesley College, Wellesley, Massachusetts, May 1974.

77. Dupree, A.K. and Foukal, P.V.: "Plasma Diagnostics from Solar EUV Spectra", presented at the IAU Colloquium No. 27, Cambridge, Massachusetts, September, 1974, and printed in the Colloquium Abstract Booklet, Pg. 17.

78. Foukal, P.V.: "The Pressure Balance and Electric Currents in Active Region Loops", High Altitude Observatory Colloquium, 12 December, 1974.

79. Foukal, P.V.: "EUV Observations of the Sun with the Harvard Spectrometer on ATM", presented at Williams College, at the Max Planck Institute (Munich), at ETH (Zürich), and at l' Institut d'Astrophysique (Liege), March, 1974.

80. Foukal, P.V.: "A New Look at the Sun from Skylab", Harvard College Observatory Public Lecture, 25 October 1974.

81. Jordan, C.: "The Intensities of Helium Lines in the Solar EUV Spectrum", presented at the IAU Colloquium No. 27, Cambridge, Massachusetts, September, 1974.

82. Noyes, R.W.: "The EUV Spectrum of Sunspots", presented at the IAU Colloquium No. 27, Cambridge, Massachusetts, September, 1974.

83. Noyes, R.W.: "Solar Astronomy from the Apollo Telescope Mount", three lectures given at Haverford College under the Phillips Visitor Program, May, 1974.

84. Noyes, R.W.: "A New View of the Sun from Skylab", Colloquium, Haverford College, May, 1974.

85. Noyes, R.W.: "Extreme Ultraviolet Observations of the Active Sun from the Harvard ATM Experiment", invited paper presented at the IAU/COSPAR Symposium on Solar Activity, Buenos Aires, Argentina, 11 - 14 June, 1974.

Papers Presented, Continued
1974

86. Noyes, R.W.: "The Sun from Skylab", invited lecture, Maria Mitchell Observatory, Nantucket, Massachusetts, July, 1974.

87. Noyes, R.W.: "The Extreme Ultraviolet Spectrum of Solar Flares", presented at the 55th Annual Meeting of the American Geophysical Union, Washington, D.C., 8 - 12 April, 1974.

88. Noyes, R.W.: "Extreme Ultraviolet Observations of Coronal Holes", presented at the Asilomar Workshop on the Solar Wind, Asilomar Conference Grounds, Pacific Grove, California, 24 - 29 March, 1974.

89. Reeves, E.M.: "ATM Observations: UV Results", invited paper presented at the IAU Colloquium No. 27, September, 1974, Cambridge, Massachusetts.

90. Reeves, E.M.: "Payload Operations Presented to the Crew Functions (Shuttle) Workshop", Johnson Space Center, Houston, Texas, 16 April, 1974.

91. Reeves, E.M.: "Solar EUV Observations from the Harvard ATM Spectrometer", XVII COSPAR Meeting, São Paulo, Brazil, 17 June - 1 July, 1974.

92. Reeves, E.M.: "A Solar Observatory in Space: Initial Results and Mission Assessments", presented at the American Astronomical Society Meeting, Los Angeles, California, 20 - 22 August, 1974.

93. Timothy, J.G.; Foukal, P.V.; Huber, M.C.E.; Noyes, R.W.; Reeves, E.M.; Schmahl, E.J.; Vernazza, J.E.; and Withbroe, G.L.: "Preliminary Results from ATM: Measurements of the Density of O_2 in the Earth's Upper Atmosphere", presented at COSPAR Meeting, São Paulo, Brazil, 24 - 29 June, 1974.

94. Timothy, J.G.: Foukal, P.V.; Huber, M.C.E.; Noyes, R.W.; Reeves, E.M.; Schmahl, E.J.; Vernazza, J.E.; and Withbroe, G.L.: "Preliminary Results from ATM: The Structure of Solar EUV Bright Points", presented at COSPAR Meeting, São Paulo, Brazil, 24 - 29 June, 1974.

95. Vernazza, J.E.; Foukal, P.V.; Huber, M.C.E.; Noyes, R.W.; Reeves, E.M.; Schmahl, E.J.; Timothy, J.G.; and Withbroe, G.L.: "ATM Measurements of EUV Intensity Fluctuations", presented at IAU Symposium No. 68, Buenos Aires, Argentina, June, 1974.

Papers Presented, Continued
1974

96. Withbroe, G.L.: "ATM EUV Observations: The Corona and Transition Region", invited paper presented at the Santa Fe Solar Physics Meeting, Santa Fe, New Mexico, 29 - 31 May, 1974.

97. Withbroe, G.L.: "Energy Balance in the Lower Corona. Implications with Regard to the Solar Wind and Coronal Heating", presented at Solar Theoretical Workshop, Kitt Peak National Observatory, Tucson, Arizona, 28 October - 1 November, 1974.

98. Withbroe, G.L.: "Recent Results from Analyses of EUV Solar Observations from Skylab", invited paper presented at the Colloquium, High Altitude Observatory, Boulder, Colorado, 19 October, 1974.

99. Withbroe, G.L.: "EUV Spectroscopy with the Harvard Skylab Experiment", invited paper presented at the Annual Meeting of the Optical Society of America, Houston, Texas, 15 - 18 October, 1974.

Papers Presented
Prior to 1974

100. Reeves, E.M.: "Ultraviolet Experiments on the Apollo Telescope Mount", presented at the Summer School on Space Optics, Marseilles, France, July, 1970.

101. Withbroe, G.L.: "The ATM Joint Observing Program", presented at the meeting of the American Astronomical Society, Solar Physics Division, the University of Maryland, College Park, Maryland, 4 - 6 April, 1972.

102. Noyes, R.W.: "A New View of the Sun from Skylab", invited paper presented at the dedication of the Harvard Science Center, November, 1973.

103. Noyes, R.W.: "Extreme Ultraviolet Solar Spectroscopy from Space", Colloquium, Princeton University, May, 1973.

SKYLAB APOLLO TELESCOPE MOUNT

S056

X-RAY TELESCOPE

Marshall Space Flight Center
Space Sciences Laboratory
Marshall Space Flight Center, Alabama

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1. SUMMARY

The conclusion of the last manned-Skylab mission marked the end of the "data take" mode of operation of the Skylab/ATM NASA-Marshall Space Flight Center/The Aerospace Corporation X-Ray Telescope (S-056) and the beginning of its "data reduction and analysis" mode of operation. The S-056 X-Ray Telescope (X-RT) and its associated X-Ray Event Analyzer (X-REA) were designed to study the morphology and physical properties of the X-ray emitting regions of the lower solar corona during the manned-observing phases of the Skylab mission. Some 27,000 filter-heliograms covering five X-ray wavelength bands between 6-47Å and one visible wavelength band centered on the Hα line were obtained by the X-RT with high-spatial (1 to 2 arc sec) and temporal resolution ($\geq \frac{1}{4}$ sec). Also, some 1100 hours of spectral data were obtained with a time resolution of 2.5 seconds using the X-REA's two proportional counter/pulse-height analyzer systems which sorted the total sun's X-ray emission into ten narrow energy channels between 2-20Å.

Concerted efforts in the reduction and analyses of these data are now underway and include the determination of the temperature of the X-ray emitting regions, using filter-ratio and channel-ratio techniques in conjunction with theoretical programs; the computation of magnetic-fields, using potential-field and constant-α force-free field theory, to determine the resemblance of X-ray emitting structures with that of the photospheric magnetic-field; the determination of emission measures (EM) and electron

densities (N_e), where $EM = \int N_e^2 ds$; the correlation of X-ray data with XUV, visble light (e.g., Hα), and radio data; the morphology and evolution of active regions, coronal holes, bright points, flares, loops, and other interesting solar phenomena; and the study of solar-terrestrial relationships. A key element in the analysis of the X-ray data is the MSFC Image Data Processing System (IDAPS), originally conceived and designed for the analysis of the S-056 data. IDAPS employs an IBM 360-65 computer for computation and image manipulation, and Interdata 70 minicomputer with additional supporting hardware for user console control (i.e., input, display, instruction, etc.), and a library of software user aids for performing a variety of image processing or data manipulation tasks.

The immense cataloguing effort which has been continuing since the spring of 1974 is now complete, with one exception, that being the determination of the exposure times for the Super Long (S^L) mode of operation frames which number several hundred. The general operations catalog (i.e., "ATM Mission Operation Log"), after many inputs from ourselves, NOAA personnel, and the other ATM experimenters, was published this summer by Ball Brothers Research Corporation. Information regarding selected solar events, as well as the experiment operations of all ATM instruments, is included in the document.

During 1974 following the transfer of Mr. J. E. Milligan from NASA/MSFC to NASA/GSFC where he assumed new duties which precluded his continuing as the S-056 Principal Investigator (PI), the two factions of the S-056 Team-i.e., NASA's Marshall Space Flight Center and The Aerospace Corporationdecided that for the purposes of the data analysis effort a "Co-PI" arrangement should be adopted. Thus, Dr. E. Tandberg-Hanssen became the S056/MSFC PI and Dr. J. H. Underwood became the S056/Aerospace PI. A memorandum of agreement or "protocol" was then documented to outline the responsibility of each of the two groups for each other as well as for the total data analysis effort. Hence, Aerospace became responsible for securing acceptable photographic/densitometric copies of all black and white film loads, and MSFC for securing acceptable photographic/densitometric copies of the color film load, as well as developing IDAPS. Both groups will jointly work together on securing calibration data and in satisfying the S056 obligation to the NSSDC.

S056/MSFC efforts include, in addition to the aforementioned tasks and investigations, performing a detailed analysis of the S056 point-spread function and of the vignetting associated with the instrument; performing a temperature profile analysis for the Skylab mission; obtaining X-REA count data and channel-ratio plots for all observed events; generating a detailed X-ray event list based on analysis of X-ray filter-heliograms, X-REA data, and H_α data; securing acceptable "PAO-type" photographs for distribution; studying the color film dye instability problem; clarifying the hue vs. wavelength (λ) response curve of the color film; and many others. The determination of the temperature profiles and X-REA count data, as well as the S^L exposure times, will come from an analysis of the tapes and printouts which are being provided by MSFC's Data Systems Laboratory. Additional remarks concerning the analysis of the S056 data appears in the joint MSFC/Aerospace report entitled "ATM

Experiment S056 Data Analysis Requirements - Revision A" (J. E. Milligan and J. H. Underwood).

Although the data reduction/analysis phase has been in progress for only a very short time, it is already apparent that the S056 data show the solar corona to be a much more dynamic plasma than suspected prior to the Skylab mission. As a result, a strong theoretical research program has been initiated to support the S056 data analysis effort. Collaborations with other ATM groups, as well as groundbased astronomy groups have proved fruitful.

2. DIRECTION OF ANALYSIS

Following the establishment of Co-PIs, the S056/MSFC group subdivided the complete data analysis and interpretation effort into two parts: An initial data reduction phase and the long-term bona fide analysis and interpretation phase.

The data reduction phase has been and will continue to be performed in close collaboration with the S056/Aerospace group. However, for practical reasons, the individual tasks or responsibilities of the two groups were divided. S056/MSFC responsibilities included: (1) developing IDAPS; (2) testing and copying the color flight film; (3) providing the experiment operations catalog for all Skylab/ATM missions; (4) analyzing the engineering parameters over the missions; (5) storing selected Skylab materials; (6) determining the point-spread function of the telescope and the effects of vignetting (due to the second step); and (7) analyzing the X-REA low-energy spill-over effect and other related problems. S-056/Aerospace responsibilities included: (1) generating the calibration notebooks; (2) measuring transmissivity of the X-ray filters; (3) performing additional calibration/sensitometric studies of the flight films; (4) copying the black and white film loads; (5) stripping the X-REA data tapes; (6) providing theoretical curves for determining temperatures, electron densities, etc. from filter-ratioing and channel-ratioing techniques; and (7) assisting in the analysis of the X-REA related problems.

The analysis and interpretation phase has progressed and is continuing to progress, to the extent possible, in parallel with the data reduction phase. All "first papers" and general presentations were jointly authored by MSFC and Aerospace staffs. Initially, the two groups worked extremely close together on specific scientific projects and in establishing approaches (i.e., team leader roles) to various types of solar-related problems. However, with the development of the Co-Principal Investigator role, the two groups began to work more independently of each other when it came to writing or presenting papers on more specific topics. Close contact was maintained between the two Co-PIs to keep each other informed and to coordinate the overall data analysis program. Collaboration between the members of the two groups has been encouraged and, indeed, joint studies involving members from both groups have now materialized. Collaborations with outside groups-both ATM groups and groundbased groups as well-have also burgeoned.

The areas of endeavor (i.e., solar phenomena) that the S-056/MSFC group has chosen to study in analyzing the S-056 data can be ranked approximately in the following manner: Morphology and development of active region; flares; prominences; transients; large-scale structure; active longitude studies; bright points; and coronal holes. Theoretical studies involving MHD theory, radiative transfer, etc., have also been initiated. In conjunction with these activities the S056/MSFC group also participated in the ATM Follow-On Study (i.e., the ATM Spacelab Facility Study) recently conducted at NASA/MSFC, and in all ATM Data Analysis Meetings,as well as the many scientific meetings (i.e., AAS, COSPAR, etc.) which occurred throughout the year. We will also generate a scientific proposal for the Coronal Hole Workshop which will occur late this year and during next year.

3. STATUS OF CONTRACTS

Over the last year four contracts for supportive solar scientific research and data analysis were let. These included contracts to The Aerospace Corporation, National Oceanic and Atmospheric Administration (NOAA), University of Alabama in Huntsville(UAH) and Teledyne-Brown Engineering Company.

Although the technical monitor for the Aerospace contract was Mr. J. E. Milligan, then Principal Investigator of the S056 instrument, the contract was let directly from the Program Office to provide more official status to Dr. J. H. Underwood who then served as the Principal Scientist of the experiment. Since the Aerospace effort grew considerably in scope throughout the year, in particular the increased responsibility of a Co-Principal Investigator, the progress performed under the Aerospace Corporation contract has been reported directly from Dr. Underwood; hence, it is not reported here.

The NOAA effort was initiated in September 1974 and was performed at NASA/MSFC with Dr. A. deLoach serving as the technical monitor and Mr. R. Wilson as his alternate. Messrs. J. Smith (Physical Scientist) and D. Speich (Physical Science Aide) were the cognizant NOAA personnel in residence at NASA/MSFC. Their activities were quite fruitful and focused on: (1) the morphology of solar active regions——their structure and development; (2) emerging flux regions and the early development of solar active regions; (3) comparison of the observed lower coronal structure with observed and computed magnetic fields; (4) comparison of the lower coronal structure with chromospheric and photospheric manifestations of active regions; (5) the physical implications of structural changes with activity; (6) the emergence of new magnetic fields within mature active regions; (7) long-period evolution of solar active regions; (8) the relationship between widely separated but closely-connected active regions; and (9) X-ray manifestations of prominence/filament eruptions. Many presentations were given at various scientific and data analysis meetings and a number of papers have been submittted to the journals for publication, or are in rough draft stages being prepared for submission to the journals. Both Mr. Smith and Mr. Speich have undertaken considerable responsibility in the areas of film calibration, photographic representation and in the use of the MSFC Image Data Processing System (IDAPS).

The UAH efforts began somewhat late in the year and have been headed-up by Dr. S. Wu. Their efforts include the development of theoretical models and computational methods for the interpretation of various solar phenomena observed with the S-056 instrument. Magnetic-field computations, using the Schmidt potential-field program and the constant-α force-free programs, have been used on the Real-Time Solar Magnetograph data and Kitt Peak National Observatory magnetograph data to determine field-line structure between active regions on the Sun. These results have been compared to the X-ray photographs of the S-056 instrument, and they have been presented at various scientific meetings or submitted for publication in the literature. Some analysis involving a one-dimensional, time-dependent, radical-flow model has also been successfully applied to the X-ray data and reported in the literature.

The Teledyne-Brown contract was initiated very late in the year, but has proven to be quite fruitful. Dr. W. Henze was the cognizant Teledyne-Brown scientist. His involvements have been to provide theoretical models of the soft X-ray coronal emission which were applied to the S-056 data to determine physical parameters of the X-ray emitting plasma on the Sun; e.g., temperatures, emission measures and electron densities. He also began investigations into the theory of nonthermal X-ray emission as related to flares and certain types of active prominence events. He also has made extensive use of the IDAPS and, in fact, has contributed to its development.

In addition to the aforementioned contracts which are continuing efforts throughout the scientific and data analysis phases of the S-056 Data Analysis Program, a fifth contract which represented the continuing efforts to develop a unique interactive Image Data Processing System (IDAPS) was let to the Systems Development Corporation (SDC). Mr. C. Cooper headed up the SDC effort. The SDC involvements were, and still are, a continuing effort to develop image data processing capability at NASA/MSFC for analyzing the S056 data. All hardware has been obtained and integrated into the system, and work has continued throughout the year on software routines for accomplishing its designed purpose. Not only has the system proven its effectiveness for the analysis of S056 data, but it has also allowed other users an additional dimension in their analysis. These outside users included Drs. R. MacQueen and A. Poland of the High Altitude Observatory S052 experiment, and many others.

4. RESULTS OF SCIENTIFIC ANALYSES

Studies of active region structure, interconnecting loops, large-scale loop structure and specific events have been initiated or completed during the last year. The initial result papers were presented at various scientific symposia and have been published in the open literature. The X-ray data have been used to study the evolution of coronal magnetic features and to obtain quantitative information about physical parameters, such as temperature and electron density. These hopefully will yield a better understanding of MHD properties of coronal plasmas. Comparisons with other correlative data, such as $H\alpha$, radio, XUV and green-line emission, have also proven valuable.

Considerable effort has been expended on the study of the 13-14 August 1973 loop, an X-ray feature which was visible for more than 50 hours and was of subflare brightness for an entire day. Our findings have been reported by Vorpahl et al. [1] and Underwood et al. [2], and a more detailed paper is forthcoming (Tandberg-Hanssen et al. [3]).

In addition, we have investigated the correlation of radio emission with X-ray emission for the September 1973 time frame (Vorpahl et al. [1] and Underwood et al. [2]); magnetic-field "reconnection" (Vorpahl et al. [1] Underwood et al. [2], and Sheeley et al. [4]); X-ray manifestations of eruptive prominences and their correlation with coronal transients (Smith et al. [5] and Gosling et al. [6]); X-ray manifestations of surges (Smith et al. [5]); long-lived coronal X-ray emitting structures with life-times of about one month (McGuire et al. [7]); oscillating bright points (Underwood et al. [2]); the structure and development of both emerging flux regions and complex active regions (Underwood et al. [2] and Smith et al. [8]); loop interconnection between widely separated active regions (Underwood et al. [2]); etc. Longer-term studies will undoubtedly reveal a wealth of solar physics information.

REFERENCES

[1] Vorpahl, J. A., Underwood, J. H., McKenzie, D. L., Milligan, J. E., and deLoach, A. C.: 1974, "Initial Results from the S-056 X-Ray Telescope on Skylab." Paper presented at the Plasma/Solar Physics Workshop, Stanford University, September 17-20, 1974.

[2] Underwood, J. H., Chapman, G. A., Janssens, T. J., Mayfield, E. B., McKenzie, D. L., Vorpahl, J. A., Walker, Jr., A. B. C., Milligan, J. E., deLoach, A. C., Hoover, R. B., McGuire, J. P. and Wilson, R. M.: 1975, "Preliminary Results from the S-056 X-Ray Telescope Experiment Aboard the Skylab/Apollo Telescope Mount." Advances in Aeronautics and Astronautics, E. Stuhlinger, S. T. Wu and M. Kent (ed.) (Am. Inst. Aero. and Astron.) (in press) (originally presented at the AIAA/AGU Space Science Conference on Scientific Experiments of Project Skylab, Huntsville, AL, 30 October-1 November 1974).

[3] Tandberg-Hanssen, E., deLoach, A. C., Hoover, R. B., McGuire, J. P., Wilson, R. M., Smith, Jr., J. B., Speich, D. M., Henze, W. and Wu, S. T.: 1975, "SKYLAB Soft X-Ray Observations of Coronal Condensations." Paper accepted for presentation ot the 146th AAS Meeting, San Diego, CA, 17-20 August 1975.

[4] Sheeley, Jr., N. R., Bohlin, J. D., Bruechner, G. E., Purcell, J. D., Scheerer, V. E., Tousey, R., Smith, Jr., J. B., Speich, D. M., Tandberg-Hanssen, E., Wilson, R. M., deLoach, A. C., Hoover, R. B. and McGuire, J. P.: 1975, "Coronal Changes Associated with a Disappearing Filament." Sol. Phys. (submitted).

[5] Smith, Jr., J. B., Speich, D. M., Wilson, R. M., deLoach, A. C. Hoover, R. B., McGuire, J. P., Wu, S. T., and Han, S. M.: 1975, "Prominence Mass Ejection and Its Effects on the Corona. I. Observations and Analysis (Radial-Flow Model)." Sol. Phys. (submitted).

[6] Gosling, J. T., Bohlin, J. D., Krieger, A. S., Schmahl, E. J. and Tandberg-Hanssen, E.: 1975, "A Review of Skylab/ATM Observations and Analysis of Coronal Transients." Invited paper presented at the 18th Plenary Meeting of COSPAR, Working Group 2, Experiments in Interplanetary Space and in the Magnetosphere, Varna, Bulgaria, May 29-June 7, 1975.

[7] McGuire, J. P., Wilson, R. M., deLoach, A. C., Hoover, R. B., Smith, Jr., J. B., Speich, D. M., and Wu, S. T.: 1975, "Long-Term X-Ray Emitting Structures in the Solar Corona." Paper presented at the 145th AAS Meeting, Bloomington, Indiana, March 23-26, 1975.

[8] Smith, Jr., J. B., Speich, D. M., Tandberg-Hanssen, E., Wilson, R. M., deLoach, A. C., Hoover, R. B., McGuire, J. P., Henze, W., and Wu, S. T.: 1975, "Results of Correlative Studies of a Complex Solar Active Region (McMath 12387) during the SKYLAB Mission." Space Research (Proceedings of 18th Plenary Meeting of COSPAR, 29 May-7 June, 1975, Varna, Bulgaria) (in press) (originally presented at the 18th Plenary Meeting of COSPAR, Working Group 3, Space Techniques as Applied to Astrophysical Problems, Varna, Bulgaria, 29 May-7 June 1975).

S-056/MSFC Publication and Presentation List

1. McKenzie, D. L. Underwood, J. H., Janssens, T. J., Milligan, J. E., and deLoach, A. C.: 1973, "Solar X-Ray Flare Observations by the S-056 X-Ray Telescope on Skylab." Paper presented at the 141st AAS Meeting, Tucson, Arizona, December, 2-6, 1973 (Abstract in B.A.A.S. 5, No. 4, Part I, 431 (1973)).

2. Mayfield, E. B., Underwood, J. H., Milligan, J. E., and deLoach, A. C.: 1973, "Observations of the X-Ray Flare of 16 June 1973 from Skylab ATM S-056 and Correlation with Magnetic Fields." Paper presented at the 141st AAS Meeting, Tucson, Arizona, December 2-6, 1973 (Abstract in B.A.A.S. 5, No. 4, Part I, 432 (1973)).

3. Walsh, E. J., Sokolowski, T. I., Miller, G. M., Cofield, Jr., K. L., Douglas, J. D., Lewter, B. J., Burke, H. O. and Davis, A. J.: 1974, "Design Characteristics of a SKYLAB Soft X-Ray Telescope." Paper presented at the Conference of Photo-Optical Instrumentation Engineers, Tucson, Arizona, March 4-6, 1974.

4. Walsh, E. J., Sokolowski, T. I., Miller, G. M., Cofield, Jr., K. L., Douglas, J. D., Lewter, B. J., Burke, H. O., and Davis, A. J.: 1974, "Design Characteristics of a SKYLAB Soft X-Ray Telescope." Proc. SPIE, 44, 175-184.

5. McKenzie, D. L., Underwood, J. H., Milligan, J. E. and deLoach, A. C.: 1974, "Initial Results from the S-056 X-Ray Telescope on Skylab." Paper presented at the International Conference on X-Rays in Space, Calgary, Alberta, Canada, August 1974.

6. Vorpahl, J. A., Underwood, J. H., McKenzie, D. L., Milligan, J. E., and deLoach, A. C.: 1974, "Initial Results from the S-056 X-Ray Telescope on Skylab." Paper presented at the Plasma/Solar Physics Workshop, Stanford University, September 17-20, 1974.

7. Cumings, N. P. and Hagyard, M. J.: 1974, "Solar Magnetic Field Measurements." Paper presented at the NASA/MSFC 2nd Annual Research Technology Review, MSFC, AL, October 8-9, 1974.

8. Cumings, N. P. and Hagyard, M. J.: 1974, "Solar Magnetic Field Measurements." Proceedings of the Second Annual Research and Technology Review, NASA/MSFC, 386-396.

9. Underwood, J, H., Chapman, G. A., Janssens, T. J., Mayfield, E. B., McKenzie, D. L., Vorpahl, J. A., Walker, Jr., A. B. C., Milligan, J. E., deLoach, A. C., Hoover, R. B., McGuire, J. P., and Wilson, R. M.: 1974, "Preliminary Results from the S-056 X-Ray Telescope Experiment Aboard the Skylab/Apollo Telescope Mount." Paper Presented at the AIAA/AGU Space Science Conference on Scientific Experiments of Project Skylab, Huntsville, AL, October 30 - November 1, 1974.

10. Meyer, R. X., Mayfield, E. B., Underwood, J. H., McKenzie, D. L., Milligan, J. E., deLoach, A. C., and Hoover, R. B.: 1974, "Analysis of Skylab/Apollo Telescope Mount S-056 Observations Based on a Force-Free Magnetic Field Model." Paper presented at the AIAA/AGU Space Science Conference on Scientific Experiments of Project Skylab, Huntsville, AL, October 30 - November 1, 1974.

11. Smith, Jr., J. B., Speich, D. M., Wilson, R. M., deLoach, A. C., Hoover, R. B., McGuire, J. P., and Wu, S. T.: 1974, "Analysis of S-056 X-Ray Data for Selected Events on the Limb." Paper presented at the Fall/AGU Meeting on Solar and Interplanetary Physics, San Francisco, CA, December 12-17, 1974.

12. Cumings, N. P., Hagyard, M. J., Smith, J. B. and Wu, S. T.: 1975, "Correlative Studies of a Complex Active Region from X-Ray, Magnetograph and H-Alpha Data during the Skylab IV Mission." Paper presented at the 5th AAS Solar Physics Meeting, Boulder, CO, January 20-22, 1975.

13. Smith, Jr., J. B., Speich, D. M., Wilson, R. M., deLoach, A. C., Hoover, R. B., and McGuire, J. P.: 1975, "Preliminary Results of Correlative Studies from S-056 X-Ray, Magnetograph and H-Alpha Data of the Complex Active Region 137/141 for June 9-18, 1973." Paper presented at the 5th AAS Solar Physics Meeting, Boulder, CO, January 20-22, 1975.

14. Underwood, J. H., Chapman, G. A., Janssens, T. J., Mayfield, E. B., McKenzie, D. L., Vorpahl, J. A., Walker, Jr., A. B. C., Milligan, J. E., deLoach, A. C., Hoover, R. B., McGuire, J. P. and Wilson, R. M.: 1975, "Preliminary Results from the S-056 X-Ray Telescope Experiment Aboard the Skylab/Apollo Telescope Mount." Advances in Aeronautics and Astronautics, E. Stuhlinger, S. T. Wu and M. Kent (ed.) (Am. Inst. Aero. and Astron.) (in press).

15. Meyer, R. X., Mayfield, E. B., Underwood, J. H., McKenzie, D. L. Milligan J. E., deLoach, A. C., and Hoover, R. B.: 1975, "Analysis of Skylab/Apollo Telescope Mount S-056 Observations Based on a Force-Free Magnetic Field Model." Advance in Aeronautics and Astronautics E. Stuhlinger, S. T. Wu and M. Kent (ed.) (Am. Inst. Aero. and Astron.) (in press).

16. McGuire, J. P., Wilson, R. M., deLoach, A. C., Hoover, R. B., Smith, Jr., J. B., Speich, D. M., and Wu, S. T.: 1975, "Long-Term X-Ray Emitting Structures in the Solar Corona." Paper presented at the 145th AAS Meeting, Bloomington, Indiana, March 23-26, 1975.

17. Smith, Jr., J. B., Speich, D. M., Wilson, R. M., deLoach, A. C., Hoover, R. B., McGuire, J. P., Wu, S. T. and Han, S. M.: 1975, "Prominence Mass Ejection and Its Effects on the Corona. I. Observations and Analysis (Radial-Flow Model)." Sol. Phys. (submitted).

18. Smith, Jr., J. B., Speich, D. M., Wilson, R. M., deLoach, A. C., Hoover, R. B., McGuire, J. P., and Wu, S. T.: 1975, "Results of Correlative Studies of the Complex Solar Active Region 137/141 (McMath 12387). Contributed paper presented at the 18th Plenary Meeting of COSPAR, Working Group 3, Space Techniques as Applied to Astrophysical Problems, Varna, Bulgaria, May 29-June 7, 1975.

19. Smith, Jr., J. B., Speich, D. M., Tandberg-Hanssen, E., Wilson, R. M., deLoach, A. C., Hoover, R. B., McGuire, J. P., Henze, W., and Wu, S. T.: 1975, "Results of Correlative Studies of a Complex Solar Active Region (McMath 12387) during the SKYLAB Mission." Space Research (Proceedings of 18th Plenary Meeting of COSPAR, 29 May-7 June, 1975, Varna, Bulgaria) (in press).

20. Gosling, J. T., Bohlin, J. D., Krieger, A. S., Schmahl, E. J. and Tandberg-Hanssen, E.: 1975, "A Review of Skylab/ATM Observations and Analysis of Coronal Transients." Invited paper presented at the 18th Plenary Meeting of COSPAR, Working Group 2, Experiments in Interplanetary Space an in the Magnetosphere, Varna, Bulgaria, May 29-June 7, 1975.

21. Sheeley, Jr., N. R., Bohlin, J. D., Bruechner, G. E., Purcell, J. D., Scheerer, V. E., Tousey, R., Smith, Jr., J. B., Speich, D. M., Tandberg-Hanssen, E., Wilson, R. M., deLoach, A. C., Hoover, R. B. and McGuire, J. P.: 1975, "Coronal Changes Associated with a Disappearing Filament." Sol. Phys. (submitted).

22. Henze, W., Reichmann, E. M., deLoach, A. C., Hoover, R. B., McGuire, J. P., Tandberg-Hanssen, E., Wilson, R. M., Smith, Jr., J. B. and Speich, D. M.: 1975, "Analysis of SKYALB Soft X-Ray Observations of Solar Active Region 131 (McMath 12379)." Contributed paper accepted for presentation at the 146th AAS Meeting, San Diego, California, August 17-20, 1975.

23. Hagyard, M. J., Cumings, N. P., deLoach, A. C., Hoover, R. B., McGuire, J. P., Tandberg-Hanssen, E., Watkins, J. R., Wilson, R. M., Smith, Jr., J. B., Speich, D. M., and Wu, S. T.: 1975, "Comparisons of Potential and Force-Free Magnetic Calculations with SKYLAB Soft X-Ray Images of a Complex Solar Active Region." Contributed paper accepted for presentation at the 146yh AAS Meeting, San Diego, California, August 17-20, 1975.

24. Smith, Jr., J. B., Speich, D. M., McGuire, J. P., deLoach, A. C., Hoover, R. B., Tandberg-Hanssen, E., Wilson, R. M., and Wu, S. T.: 1975, "SKYLAB Soft X-Ray Observations of Magnetic-Field Reconfiguration." Contributed paper accepted for presentation ot the 146th AAS Meeting, San Diego, California, August 17-20, 1975.

25. Tandberg-Hanssen, E., deLoach, A. C., Hoover, R. B., McGuire, J. P., Wilson, R. M., Smith, Jr., J. B., Speich, D. M., Henze, W. and Wu, S. T.: 1975, "SKYLAB Soft X-Ray Observations of Coronal Condensations." Contributed paper accepted for presentation at the 146th AAS Meeting, San Diego, California, August 17-20, 1975.

26. Underwood, J. H., Milligan, J. E., deLoach, A. C., Hoover, R. B., and Wilson, R. M.: 1975, "The S-056 X-Ray Telescope Experiment on the SKYLAB-Apollo Telescope Mount." Space Science Instrumentation (to be submitted).

SKYLAB APOLLO TELESCOPE MOUNT

S056

X-RAY TELESCOPE

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Summary Report of S-056 Data Analysis
Carried out at The Aerospace Corporation

The first data from the ATM S-056 x-ray telescope experiment on SKYLAB became available in July 1973, shortly after the splashdown of the first mission. Prior to that time, scientists in the Space Physics Laboratory of The Aerospace Corporation had been making preparations for the reduction and analysis of the data (as well as providing support for the SKYLAB missions at JSC), and with the receipt of the first data, began work on the analysis proper, a task which has continued ever since.

Instrument Description

The prime instrument in the S-056 system was an x-ray telescope which used a glancing incidence imaging element of Wolter's type 1 to form an image of the sun on a film in the focal plane. The glancing angle of incidence chosen for the telescope (0.916°) enabled it to function from a short-wavelength limit of 6 Å on upward. Wavelength bands of interest in the range from 6 to 50 Å were isolated by five thin foils of metal located on a filter wheel directly in front of the film plane. X-ray exposures through these filters could be taken in pre-programmed (automatic) or manual sequences, with the lengths of exposure determined on the basis of the degree of solar activity at the time, and the particular scientific program (JOP) in progress. The film was carried in a replaceable cassette in 1000 foot rolls. Five such rolls (four black-and-white, one color) were exposed during the ATM mission, resulting in a total of 27,000 solar x-ray exposures.

In addition to the x-ray telescope, the S-056 package contained a whole-sun flux monitor consisting of two proportional counters to measure the solar x-ray flux in the ranges 2-8 Å and 8-20 Å. This instrument was intended primarily to measure the flux from transient solar events such as flares, hence it was termed the x-ray event analyser or X-REA. Data from the X-REA were telemetered to the ground and recorded on magnetic tapes.

Data Reduction and Analysis - Film

Before detailed analysis and interpretation of the film images could be started, a certain amount of preparatory work had to be carried out. In particular, calibration of the x-ray sensitive films (as well as the rest of the telescope system) had to be completed and accurate copies, suitable for reproduction and microdensitometry had to be made.

Since the unsupercoated SO-212 black-and-white film is delicate and easily damaged during handling, a decision was made to do most of the analysis, including microdensitometry, on accurate second-generation copies of the originals. Since the density of the originals ranged up to 4.0, copying presented a difficult task. Early attempts at copying made by the photo group at JSC resulted in inferior copies, and in May 1974 the film was transferred to Aerospace for copying. An optical printer was modified to make continuous contact copies with no risk of damaging the originals. Many film-developer combinations were tested until one was found which enabled the large dynamic range of the original to be reproduced. It was found that 5235 film, when properly developed, exhibited an H-D curve with a long straight-line region. Even so, it was found that two copies, with a high and low exposure, were required to reproduce both bright and faint x-ray details on the original. At the present time, copying is still being carried out to satisfy the requirements of the MSFC group and the National Space Science Data Center. Also, third and subsequent generation copies are being produced as well as pictorial material for study and analysis, slides, presentations, etc.

The program for calibration of the x-ray telescope has involved the determination of the film sensitivity in the x-ray region as a function of wavelength, the measurement of telescope efficiency and filter transmission, and the determination of the instrument point spread function and geometrical parameters. This program is complete in all except a few details to be resolved in the next few months by a joint effort between The Aerospace Corporation and the Space Sciences Lab at MSFC.

Accurate microdensitometry of the films is required in order to find the energy flux from a particular solar region. By measuring the ratio of the energy deposited on the film in two wavelength bands (corresponding to two different filters) it is possible to obtain estimates of the temperature and density of the plasma within such a region. The procedure requires a knowledge of the solar x-ray spectrum and its variation with temperature. Since observations of the solar x-ray spectrum with sufficient spatial and spectral resolution were not made during the period of the SKYLAB mission, we must rely on theoretical calculations of the spectra. A program to carry out such calculations has been developed at Aerospace over the last several years, for application to the S-056 data and to other space x-ray data. This program includes all processes which are known to affect the x-ray emission from a high temperature plasma, and uses the most up-to-date values of abundances and of atomic parameters. The first applications of the results of these calculations to the S-056 x-ray data have yielded interesting and encouraging results.

Data Reduction and Analysis - X-REA

A considerable amount of effort had to be devoted to the reading of the X-REA tapes on the computer because of unforseen problems (e.g. parity errors) with these tapes and the data they contained. All tapes have now been read and the X-REA data displayed on plots, averaged for one minute, each plot covering a period of 6 hours. A program for recovering the detailed time profile of the X-REA signal for special events such as flares has just been completed. Also, the results of the x-ray spectral program, mentioned in the previous section, have been applied to the X-REA, so that it is possible to determine the physical parameters inside coronal regions which produce x-ray transient events.

The X-REA analysis is complicated by some anomalies in the operation of the proportional counters. The counters suffered a decrease in gain over the period of the 3 SKYLAB missions. Also, an anomalously high count rate in the lower channels of the two counters renders the data from these channels suspect. The personnel of The Aerospace Corporation Space Physics Laboratory and the MSFC Space Science Laboratory are jointly pursuing a solution to these problems.

Data Interpretation and Scientific Results

The x-ray images and the X-REA data have been studied intensively since they first became available, and a number of results of importance to solar coronal physics have been obtained. These results have been presented at meetings and symposia over the past two years, and some have also appeared in scientific publications. A publications and presentations list is attached herewith. Some of the more important findings are summarized below:

Flares

The images of almost 200 flares, subflares and flarelike transient brightenings were recorded by the x-ray telescope. 132 of these were studies in detail to determine the characteristic structure and evol ution of the x-ray emitting portion of a flare. The data indicated that the soft x-rays came primarily from an intense, well-defined core surrounded by a region of fainter, more diffuse emission. Loop structures were found to be a fundamental characteristic of flare cores and arcades of loops were found to play a more important role in the flare phenomenon than had previously been thought. The size distribution of flare x-ray loops was determined and a classification scheme describing the brightest features was developed. An analysis of flare eovlution provided evidence for preliminary heating and energy release prior to the main phase of the flare. A detailed study of the flare of 5 September 1973 with g sec time resolution allowed the site of the initial energy release to be located and also provided detailed information about the evolution of the flare itself. The observations showed that the flare occurred in an arcade of loops rather than any single loop. The sequential brightening of the features indicated that some excitation mechanism moved perpendicular to the magnetic field of the arcade at 180 - 280 km/sec. A magnetosonic wave was suggested as a mechanism by which the disturbance may have been propagated. Study of these events continues, with emphasis on the determination of the physical parameters (temperature and density) in the flaring region. A number of unusual transient events have been observed in the film images. An event lasting more than 24 hours, with a rise time of several hours was observed on August 13-14 1973. This type of event is rare in the data but seems to be exemplary of a "slow flare" in which the usual flare processes take place over a much longer time. At the other end of the time scale, small rapid brightenings are frequently seen, often at the feet of large loops or magnetic arcades. One case of bright points at opposite ends of a loop oscillating in brightness in anti-phase has been observed. These fluctuations are believed to be due to hydromagnetic waves propagating along the loops.

In another instance, a coronal structure was observed from a short spike into a complete arch-like structure within an 8 minute period. Such phenomena have not been observed in visible coronal emissions, so that their discovery in the x-ray data provides a new insight into coronal transient processes.

Active Regions

As the x-ray emission from the corona is not masked by light from the photosphere, it is possible with the x-ray photographs to observe the structure of the corona over active regions which are on the disc. Furthermore, it is possible to study the development of such regions as they pass across the disc, and to correlate such development with that of the associated photospheric magnetic field structure. We have carried out such studies for selected active regions, comparing the morphology of the coronal structures with the coronal field computed from line-of-sight magnetograph measurements. Both potential and force-free approximations were used for the field calculations. In general, the observed coronal x-ray structure, which usually consists of loops and arches, frequently arranged into arcades, corresponds well to the potential field expected from the photospheric magnetic field, but in a few cases the force-free approximation gives better correspondence. The lifetime of the individual components of the active region structure is of the same order of magnitude as that of the underlying field. Coronal reconnection between rapidly developing regions, such as emerging flux regions, has been observed.

Temperature determinations, by the method outlined in a previous section, have been made for a number of active regions, resulting in temperatures between 3 and 6 million degrees. The results of these determinations are being applied to a determination of the energy balance of hot coronal condensations. As in the case of the flares and transients, a number of unusual phenomena have been noted in the study of active regions. The sharp interface between the hot dense parts of some active regions and neighboring small coronal holes is particularly interesting as is the association of these features with prominences.

Quiet Sun

Good observations of coronal holes were obtained on the first and second SKYLAB missions, making a study of the evolution of these features possible. The growth of a hole near its interface with an active region is particularly interesting, as it reflects the interaction of the hole magnetic field with that of the active region. During June 1973, a particularly striking example of such an interaction occurred, and this event is being studied intensively.

Other large scale features of the solar corona which may be seen in the x-ray photographs include rays, streamers, and large loops. The loops have been shown to be responsible for sympathetic radio and soft x-ray bursts. Apparently the bursts are triggered by streams of particles which travel along the loops. The magnetohydrodynamics of such structures, as well as the other features which occur frequently in the x-ray photographs, are under theoretical study at Aerospace.

List of Papers and Presentations Concerning S-056
with Aerospace Personnel as Primary Authors

1. "Extreme Ultraviolet and X-ray Telescope," J. H. Underwood, Presented at Meeting of Solar Physics Division, AAS, Honolulu, Hawaii, January 1974.

2. "Force-Free Magnetic Fields in the X-ray Flare of 16 June 1973", R. X. Meyer and E. B. Mayfield, Presented at meeting of Solar Physics Division, AAS, Honolulu, Hawaii, January 1974.

3. "Solar X-ray Features and Events," T. J. Janssens, G. A. Chapman, A. C. DeLoach, D. L. McKenzie, J. E. Milligan and J. H. Underwood. Presented at meeting of Solar Physics Division, AAS, Honolulu, Hawaii, January 1974.

4. "Results from the Extreme Ultraviolet and X-ray Telescope on the Skylab-Apollo Telescope Mount," J. H. Underwood, Presented at AIU-COSPAR Symposium No. 68, "Solar X, γ, and EUV radiation, "Buenos Aires, Argentina, June 1974.

5. "Initial Results from the S-056 X-ray Telescope on Skylab," D. L. McKenzie, J. H. Underwood, J. E. Milligan, A. C. DeLoach. Presented at International Conference on X-rays in Space, Calgary, Alberta, Canada, August 1974.

6. "Results from the S-056 Telescope", J. A. Vorpahl, J. H. Underwood, D. L. McKenzie, J. E. Milligan, A. C. DeLoach. Presented at Stanford Plasma/Solar Physics Meeting, Stanford, California, September 1974.

7. "Preliminary Results from the S-056 X-ray Telescope Aboard the Skylab-Apollo Telescope Mount," J. H. Underwood, G. A. Chapman, T. J. Janssens, E. B. Mayfield, D. L. McKenzie, J. A. Vorpahl, J. G. McGuire, R. M. Wilson, AIAA/AGU Conference on Scientific Experiments of Skylab, Huntsville, Alabama, October 30 - November 1, 1974.

8. R. X. Meyer, E. B. Mayfield, J. H. Underwood and D. L. McKenzie (The Aerospace Corp.) and J. E. Milligan, A. C. DeLoach and R. B. Hoover, (M. S. F. C.), "Analysis of Skylab/Apollo Telescope Mount S-056 X-Ray Observations Based on a Force-Free Magnetic Field Model", AIAA/AGU Space Science Conference (in press).

9. "Observations of the Structure and Evolution of Solar Flares with a Soft X-ray Telescope," J. A. Vorpahl, J. H. Underwood, E. G. Gibson, P. B. Landecker, D. L. McKenzie (in press).

10. "The Triggering and Subsequent Development of a Solar Flare," J. A. Vorpahl. Submitted for publication in Astrophysical Journal Letters.

SKYLAB APOLLO TELESCOPE MOUNT

S082

XUV SPECTROGRAPHY/SPECTROHELIOGRAPH

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Introduction

In the year-and-a-half since the splashdown of SL/4 a great deal has been accomplished with the S082 data. Returning from JSC, starting-up analysis, assessing the impact of ATM on NASA programs, such as Shuttle, and public relations have required much time. Nevertheless, I am well pleased with the progress we have made. The growing list of publications and talks speaks for itself.

Of greatest importance are the new results on solar flares. The unsurpassed spatial and spectral resolution of the NRL XUV results has provided critical views of flare structure never before seen. Monochromatic flare images and flare spectra were photographed in emissions of temperature ranging from the low chromosphere up to twenty million degrees where the flare energy is first released. Details in the structures as small as 1500 km, and velocities from a few tens to 1000 km/sec, can be separated and followed from one temperature region to another. A new picture of the solar flare and understanding of the dynamic physical processes which control it are emerging.

We have also recorded for the first time eruptive prominences, not simply in the relatively cool chromosphere, but also in regions of higher temperature, even into the corona. These spectacular eruptions vary widely in form and type; their connection with flares, x-ray events, and terrestrial effects were well observed, but are as yet far from explained.

Among new or more fully recognized phenomena are the XUV bright points, the XUV polar plumes, the macrospicules, and the "coronal" holes which NRL's results show extend far below the corona and are accompanied by a thickened, bright solar limb. Precise intensity calibration is progressing well. The first synoptic observations of the uppermost part of the ozone layer were made.

These highlights of our analysis to June 30, 1975 provide a glimpse into the enormous wealth of new information that lies before us as a challenge. From today's perspective, the magnitude of the task as described in our original proposal was underestimated, perhaps by as much as a factor of two. I would now judge that at the end of five years we shall have analyzed only about half of what we have. And the most important phase is yet to come - collaboration by the ATM investigators with each other, and with ground-based observers. Only after several years will we really be able to undertake the final task of interpretation.

The implication is that adequate, on-going funding will be needed to carry the analysis of ATM data through interpretation. The increased consideration that NASA has been giving the support of data reduction is encouraging, but if the great promise to solar physics contained in the ATM data is to be realized, it is essential to plan for a long-range and thorough program of data analysis and interpretation.

R. Tousey

R. Tousey

1. Flares

S082A Images

Monochromatic XUV flare images, unique in character, have clearly and unambiguously revealed for the first time the location of the high-temperature flare relative to the magnetic field structure and the chromospheric ribbons. With a spatial resolution approaching 1500 km, the structural components in flares, ranging in temperature from 20,000 to 20 x 10^6 °K, their velocities, physical relationships and parallel development in time, have been determined.

The basic magnetic field configuration has been found to be a low-altitude (4,000 to 13,000 km) arch in a bipolar magnetic field region. The hot flare plasma, heated to temperatures in the range of 10 to 20 x 10^6 °K has been located near the top of the arch, lying between volumes of cooler plasma near the feet of the arch, which form the "flare ribbons." It has been inferred from this thermal stratification along the arch, that the primary energy release in a flare is cospatial with the high temperature region (Fe XXIII and XXIV emission), and that energy is transferred downward along the legs of the arch by conduction or fast particles.

S082B Line Spectra

Broadening of profiles, Doppler shifts and asymmetries, especially of lines formed in the transition region 100,000 to 300,000 °K, have been found, prior to flares and lasting well into the post-maximum phase.

The corresponding disturbances and mass motions have been found, on simultaneous S082A spectroheliograms, to be confined to small areas which may be the footpoints of the flare arch.

Density and Temperature

The volumes of Fe XXIII and XXIV flare images have been measured and, typically, electron densities of about 10^{11} cm^{-3} have been derived. In small bright cores, the density has been found to be significantly higher, about 10^{12} cm^{-3}, depending on the estimate used for the lower limit of their size.

During the flash phase, temperatures in the range of 20 to 60 x 10^6 °K have been determined from Doppler broadening of the cores.

Flare-Like Events

Gradual Rise-and-Fall (GRF) Events

Although generally similar to flares, GRF X-ray and microwave events are of longer duration, have lower peak temperatures (~6 million degrees), and show only weak chromospheric brightenings in Hα and He II.

In collaboration with other ATM groups, a study has been made of corresponding observations during GRF events. They have been found to be the manifestation of an event where a coronal transient accompanies the heating of a bright X-ray emitting structure, which later tends to resolve into classic "post-flare loops" as it cools.

Other Flare-Like Events

One hundred events have been found in the S082A and S082B data which show flare-like properties but are not associated with conspicuous enhancements in the 1-8 Å X-ray flux.

In S082A spectroheliograms, the cores of these events are compact, very bright, and visible in many lines similar to flares, including, at times, some high temperature lines. In S082B spectra, lines are intense, broadened, and may show asymmetry, indicating some kind of mass streaming.

Dynamical effects, rather than heating, appear to be indicated.

Theoretical and Numerical Models

A new flare model has been developed, and the properties of a magnetic arch under a variety of magnetic and current configurations (including force-free) have been theoretically investigated for both the static and flaring state.

The temporal and spatial spread of conductive energy from the top of the arch has been numerically modelled, and various diagnostic parameters, such as line radiation, bremsstrahlung, and emission measure, have been predicted for comparison with S082A and S082B flare observations.

2. Eruptive Prominences

Eleven EPL's were observed by S082A during the mission. The number observed is surprisingly great, and several have received wide publicity because of their spectacular character. In ten, mass ejection events were also observed by S052 and, in about half, gradual rise-and-fall events were recorded in X-rays (SOLRAD) and 2800 MHz radio.

There is great diversity both in the character of the EPL's and their relation to flares. The two extreme types are: the slow but tremendous eruption of one of the largest prominences of a decade, observed in He I, II, and O V, on December 19, 1973; and, on January 17, 1974, the most energetic of all, and the only one recorded in coronal lines of temperatures up to 3.5×10^6 °K (Fe XVI).

The study of all these events is in the phenomenological stage, where correlations with the white light corona, X-rays, and ground-based observations are still being made. Each event is so different and exhibits such a wealth of detail that it is a separate project in itself. After photographic calibration is completed, the quantitative determination of the spatial distribution of densities and temperatures will be commenced.

3. Active Regions and Magnetic Fields

The high-resolution S082A spectra have enabled us to make detailed and extensive comparisons between high-temperature images and magnetograms, from which the extension of photospheric magnetic fields up into the corona has been determined.

The coronal field structure around active regions has been reconstructed by combining images in spectral lines emitted by ions formed at different temperatures, in particular, Fe XV ($\sim 2.5 \times 10^6$ °K), Mg IX ($\sim 10^6$ °K) and Ne VII ($\sim 0.5 \times 10^6$ °K). Each ion has been found to trace out most vividly that part of the structure crossing the region of the corona within its temperature range, the whole comprising a pattern of loops of emission whose tops arch across neutral lines, and whose feet terminate in regions of opposite magnetic polarity. The tops of the loops are most apparent in the high temperature line of Fe XV, the feet and lower legs are most apparent in the relatively low temperature line of Ne VII, and Mg IX appears strongest along the loops between these extremes. A diffuse sheath, seen in the hotter lines appears to envelop a more slender core, seen in the cooler lines.

Although the corona is a highly conducting plasma, the resulting field structures have been found to resemble closely the forms expected from magnetic potential fields, whose sources are current loops at or below the photosphere, interacting and reconnecting in a vacuum. The coronal fields appear to respond to motion of their footpoints with readjustments toward a simple, lowest-energy state.

Coronal structures have, however, been found which are distorted from the form outlining a potential field. Numerous cases have been found where such distorted structures have been replaced by the coronal loops of potential fields, following the eruption of an associated prominence. These results suggest that the distortions were due to the weight of the prominence material on supporting field lines. A coronal transient and a gradual rise-and-fall of X-ray flux have been found frequently to accompany such events, suggesting that the excess magnetic field energy is expended in heating, as well as accelerating material.

4. The Quiet Sun

Chromospheric Network

From S082A spectroheliograms, the XUV emission from ions formed under 10^6 °K has been found to be concentrated along the supergranulation boundaries, which are also the location of chromospheric spicules. (Just how spicules are related to this emission is not clear; the resolution (≈2 arc sec) is not really sufficient to discount the model where spicules are surrounded by a thin transition layer, in favor of, for example, a cloud-like distribution of the emission around the spicules).

An abrupt change in appearance has been found, in lines formed above 10^6 °K (e.g., Mg IX 368 Å), from a relatively well-ordered chromospheric network to a diffuse cloud-like pattern in which the large scale network is barely recognizable. This dramatic change indicates that the magnetic fields concentrated in the chromospheric network boundaries experience an abrupt spreading as they enter the low corona, which supports the model which was proposed some years ago.

Coronal Holes

A phenomenological study of the large scale evolution and structure of the holes is in progress. The boundaries of all the holes for the entire manned portion of Skylab have been measured from the He II 304 Å synoptic images. These data have been plotted by computer on both Mercator and polar-view formats, and large scale versions of the maps themselves will be published as a NOAA UAG report. A result is that coronal holes have been found to occur in large unipolar magnetic regions, confirming the "open field" model of their formation. The question now is why all large unipolar regions don't become coronal holes.

A collaboration with U. California radio observers has resulted in the conclusion that coronal holes at high solar latitudes correlate well with the source of high-speed streams in the solar wind at high latitudes as inferred from radio scintillation observations.

Polar Plumes

A detailed study of polar plumes is in progress. The spectral identifications are finished, with 42 XUV lines observed and identified; of these, new solar identifications for Al VIII and IX, and Na VIII have been found. These monochromatic plume images show a temperature for plumes of 0.7 to 1.1×10^6 °K, which corroborates the value found from eclipse studies. The next step is to derive coronal abundances for the ions Ne, Mg, Si, Na, Ca, Al and Fe. A preliminary density distribution derived for the XUV plumes is in identical agreement with that for white light plumes.

Solar Poles

A preliminary study of the phenomena at the solar poles in general has been completed. The apparently anomalous broadening of the Ne VII 465 Å limb and the extended appearance of Mg IX polar plumes was shown to be a direct consequence of a lower transition zone temperature gradient an isothermal corona at $\sim 10^6$ °K over the polar coronal hole.

Macrospicules

A phenomenological study of He II 304 Å macrospicules has been finished. It was shown that they are a new solar feature, unique to coronal holes, and of sizes and dynamics greatly exceeding the well-known Hα spicules. A comparison has been made of the macrospicules observed in He II 304 Å images around the solar poles with Hα spicules observed simultaneously. No correlation could be found.

Bright Points

Two kinds of bright points have been found. Monopolar bright points, or emission features, correspond to bright segments of the chromospheric network where the unipolar magnetic field is significantly higher than average. These monopolar bright points are observed in the transition region line Ne VII 465 Å but are not visible in the hotter coronal lines such as Fe XV. Bipolar bright points appear to be loops connecting the poles of the bipolar magnetic fields observed on magnetograms, and are associated with the X-ray bright points seen on ATM X-ray pictures. They are bright in the hot lines such as Fe XV, but lessen in intensity through the transition region lines.

5. Line Identifications

The S082A and S082B data have led to the new identification of a number of high-temperature flare lines, as well as to quiet-sun lines such as the Si lines below 1700 Å. These lines are precision diagnostic tools for determining temperatures, densities, abundances and velocities, and for testing the degree of departure from ionization equilibrium in the varying plasma conditions of solar features. They have extended our ability to determine temperatures up to about 30×10^6 K. They have provided information about ionization equilibrium at the site of the energy release over the life-time of a flare.

Fourteen flare lines have been analyzed. Along the lithium iso-electronic sequence, the intensity-histories of the doublet ($2s^2\,S$ - $2p\ ^2P$) lines of Ar XVI, K XVII, Ca XVIII and Fe XXIV in the S082A data, have confirmed their previous identification, and improved wavelengths have been determined. Along the beryllium iso-electronic sequence, new ($2s^2\,{}^1S_0$ - $2s2p\ {}^3P_1$) lines of Ar XV, Ca XVII, Cr XXI, Mn XXII, Fe XXIII and Ni XXV have been observed and classified. Of these, the Fe XXIII line at 263.7 Å is the strongest. Its classification established the relative energy of the single and triplet systems for the first time. In the S082B data, new forbidden lines of Fe XVIII, Fe XIV, and Fe XXI have been identified. From the profiles of Fe XIX and Fe XXI lines, analysis of Doppler and temperature broadening has indicated that ionization equilibrium was established during the cooling phase of the flare of June 15, 1973. Ionization equilibrium during the heating phase has not yet been determined.

At least six high-temperature flare lines identical in appearance to Fe XXIII and Fe XXIV remain to be identified in the S082A data.

The relative intensities of these flare lines can be used, for example, to obtain solar abundances of rarely-studied elements. The problem of the discrepancy in the relative abundance of Argon and Calcium in the solar corona, as determined from observations of X-ray resonance lines of Ar XVII and Ca XIX near 3 Å, and forbidden lines of Ar X, Ar XIV, Ca XII, Ca XIII and Ca XV in the visible, is open to review with our new identification of Argon and Calcium lines in the XUV spectrum.

6. Limb Spectra

Spectra, taken by S082B at various limb positions, above an active region, a quiet region and a polar coronal hole, have been compared. A number of lines, emitted by ions formed in the transition zone at temperatures between 36,000 and 220,000°K have been selected from the wavelength range 1100-2000 Å. Their intensities, as well as the widths and profiles of those that are optically thin, have been measured, and limb brightening curves generated.

These lines have been found to rise in intensity abruptly, and peak between +2" and +4" above the limb. In general, emission from above the quiet region is more intense than from above the coronal hole for heights below +6". Above +8" the situation is reversed, and substantial emission occurs out to, and beyond +12" above the coronal hole.

Ratios of emission, in various lines, to that in the resonance lines of N V have been compared at different heights. A systematic decrease of these ratios with height has been found, less noticeable above a coronal hole until beyond +8". The rate of decrease is more pronounced for lower temperature lines, and this effect is most noticeable above the coronal hole.

These results are now being compared to theoretical predictions of coronal heating models.

7. Atmospheric Extinction

Solar spectra were taken through varying pathlengths of the earth's atmosphere by the calibration rockets and S082B. The SKYBET tapes required for accurate determination of pathlengths for the S082B data have been recently received. Three principal results have been obtained so far: the first synoptic measurements of the ozone layer in the altitude region 65 to 85 km; an improved density profile for molecular oxygen in the altitude region from 75 to 120 km, showing a higher density below 90 km, and a lower density above 95 km than previous models; many lines of the molecular oxygen Schumann-Runge bands between 1750 and 2000 Å have been resolved for the first time in the earth's atmosphere.

8. Calibration

S082A

From microphotometry of spectra of the National Bureau of Standards Synchrotron, taken before and after flight with the calibration rocket A instrument, the relationship between film densities and absolute intensities has been derived. To determine the contribution of higher-order spectra overlying the longer wavelengths, due to the relatively high intensity of the synchrotron and the transmission of the aluminum filter at short wavelengths, the reflectance of the grating has been remeasured.

The transfer of absolute calibration to S082A, by comparison of the microphotometry of the calibration rocket images and S082A images taken almost simultaneously, is nearly completed for SL/4. Calibration for SL/2 and SL/3 will then be carried out.

A study is underway to compare the sensitivity of S082A at several points in the mission, using the He II 304 Å images, and the quiet network as a "constant" source, to extend the absolute calibration to the entire mission.

S082B

The relationship between absolute intensity and film densities at various wavelengths has been derived for all three calibration rocket B instruments, using spectra taken of an absolutely calibrated deuterium lamp and a nitrogen lamp before and after flight. The recently perfected Argon continuum standard, developed at the National Bureau of Standards, is being used to extend the absolute calibration over the wavelength range 1250 to 1700 Å.

The transfer of this absolute calibration to S082B, by comparison of solar spectra taken by the rockets and S082B almost simultaneously has been carried out for several wavelengths.

Comparison of the sensitivity of S082B, using "slew calibration" spectra taken at many points throughout Skylab at a number of wavelengths is nearly completed. It has been found that the film characteristics for the three missions are different, and the use of all three calibration rockets together with the "slew" calibration has been needed to extend the absolute calibration to the entire mission.

9. Comet Kohoutek

The Comet Kohoutek Ly α observations were reduced and analyzed, in collaboration with Uwe Keller. The line width was found to be compatible with the theoretical outflow velocity for hydrogen from a comet nucleus.

10. Ionization Equilibrium Functions

An improvement has been made in calculations used to interpret XUV spectra, to include the effects of the surrounding plasma on the dielectronic recombination process. Ionization equilibrium calculations, as a function of the local plasma temperature and density, have been carried out for the ions of Ne, Na, Mg, Al, Si, Ca and Fe, taking into account collisional ionization (both direct and via excitation of autoionizing levels), collisional recombination, radiative recombination, and dielectronic recombination. Radiative excitation and ionization processes have been neglected. Gaunt factors, electron impact excitation cross sections, and rate coefficients, for allowed and forbidden transitions of high ionization stages of Fe, Ne, Mg, Al, Ca, Si and Ni have also been calculated, in the distorted wave approximation. (Also available, with the aid of a minor calculation, are the radiative life times and oscillator strengths for the spectral lines of interest.)

Except in the case of Fe, where dielectronic recombination accounts for as much as 20% of the total radiative energy loss rate, good agreement has been found between the preliminary results and previously published work. A theory has been developed to incorporate the effects of long-range electric fields from collective plasma modes excited by non-thermal effects, which can be dominant over local thermal fields. This modification, as well as a more detailed specification of the atomic structure , which takes into account the LS-coupling, or fine-structure, of the ions for selected transitions (within the framework of the central field approximation) is being included in the calculation of both the dielectronic recombination and radiative recombination coefficients.

11. Laser Studies

In the rapidly changing conditions of solar flare plasmas, ionization equilibrium is not always valid. Laser spectroscopy has been undertaken to help identify new high-temperature solar lines, and to test experimentally the large body of atomic theory available to calculate physical parameters, such as electron density and temperature, under transient conditions.

Taking advantage of high-power lasers here at NRL, very high intensity light pulses have been focused onto appropriate targets, and the emission from the resulting high-temperature plasma has been measured and compared with non-equilibrium theory. X-ray line spectra, grazing-incidence XUV slit spectra, XUV spectral images (similar to those obtained from S082B), and normal incidence UV slit spectra covering the wavelength range from 2 to 2000 Å, have been acquired from very short-lived ($\sim 10^{-10}$ sec) plasmas with relatively simple dynamic geometry.

The results have been tested against the theory, and modifications to the theory are being explored. This new understanding will be applied to calculations for the rapidly-changing high-temperature plasmas on the sun.

12. Atlas

XUV Monitor

An atlas of XUV monitor images from TV downlinks is in final review. The atlas includes a daily half-second integration image to show brighter features, and a two-second integration image to show coronal holes and fainter features on the disc.

S082A

A card file on S082A plates, listing some twelve categories of phenomena, has been completed, to be used in collaborations as well as in our own studies. This effort led to issuing an interim listing of plasma ejection events and solar flares observed by S082A to the other ATM groups. These lists will be expanded.

13. Engineering Data Books

The Engineering data books have been received for S082A for all missions, and S082B for SL/3 and SL/4, with the SL/2 volume in press.

14. Photographic Support

Special photographic techniques have been developed to reproduce, in forms best suited for scientific interpretation, the large amount of information stored on the NRL film. These prints have often reduced the amount of densitometry needed in preliminary analysis. Advances are continuing in these techniques.

The approach for high-fidelity reproduction of the flight film has been established. NRL will undertake printing of slightly-less-than 2X enlargements on rolls of 70 mm film. NSSDC will carry out the processing, and generate all copy negatives for users. A "Users Guide", or reference manual of pertinent data will be supplied by NRL.

15. Densitometer Support

The NRL densitometer is in use full-time for all critical measure ments of spectral lines and images in the quantitative analysis of the S082A and S082B data.

16. Computer Support

With some support from GSFC, sufficient computer time has generally been available.

17. Image Enhancement

Two possibilities for enhancing S082A images have been identified: the subtraction of overlapping images, and the focusing of lower resolution images far from the grating normal. A number of images have already been digitized. Image processing and enhancement is being explored with facilities at NRL and also with the IDAPS at MSFC.

ATM BIBLIOGRAPHY

20 August 1975

(Commences with the initiation of the ATM Project and includes all publications and papers based on S082A and B material up to the present.)

1457 "Apollo Solar Experiments - Paving the Way for Advanced Space Observatories", Winter, T. C., Jr. 1969, Astronautics and Aeronautics, March, p. 64.

1481 "Observations of the Extreme Ultraviolet Solar Spectrum", Tousey, R. 1971, in 'A Discussion on Solar Studies with Special Reference to Space Observations', Phil. Trans. Roy. Soc. Lond. A 270, 59. (Invited)

1489 "Semi-Automatic Acquisition of Extrme Ultraviolet Reflectance Data for Calculating Optical Constants", Hunter, W. R. 1970, Rev. Sci. Instr. 41, 1419.

1502 "Spectral Radiance of the Carbon Arc Between 2500 Å and 1900 Å", Pitz, E. E. 1971, Appl. Opt. 10, 813.

1515 "Survey of New Solar Results", Tousey, R. 1971, in 'New Techniques in Space Astronomy', IAU Symp. 41, 223, ed. F. Labuhn and R. Lust, Reidel, Dordrecht.

1517 "High Angular Resolution Absolute Intensity of the Solar Continuum from 1400 Å to 1790 Å", Brueckner, G. E., and Moe, O. K. 1972, Space Research XII, Vol. 2, 1595, ed. S. A. Bowhill, L. D. Jaffe, and M. J. Rycroft, Akademie-Verlag, Berlin.

1518 "Solar Spectroscopy from Space Vehicles", Tousey, R. 1972, in 'Developments in Applied Spectroscopy', Vol. 10, 191, ed. A. J. Perkins, E. L. Grove, E. F. Kaelble and J. E. Westermeyer, Plenum, New York. (Invited)

1522 "High Angular Resolution Observations from Rockets: Solar XUV Observations", Tousey, R. 1972, Space Research XII, Vol. 2, 1719, ed. S. A. Bowhill, L. D. Jaffe, and M. J. Rycroft, Akademie-Verlag, Berlin. (Invited)

1529 "On the Classification of Some Highly Ionized Iron and Nickel Lines in the 200-400 Å Region of the Solar Spectrum", Widing, K. G., Sandlin, G. D., and Cowan, R. D. 1971, Astrophys. J. 169, 405.

1548 "Simultaneous Optical Monitoring of Angular and Translational Alignment", Bohlin, J. D. 1972, Appl. Opt. 11, 961.

1549 "Extreme Ultraviolet Solar Images Televised In-Flight with a Rocket-Borne SEC Vidicon System", Tousey, R. and Limansky, I. 1972, Appl. Opt. 11, 1025.

1566 "Rocket Observation of Ar XII-XVI and Ca XIV-XVIII in the XUV Spectrum of a Solar Flare", Purcell, J. D. and Widing, K. G. 1972, Astrophys. J. 176, 239.

1570 "Cleaning of Contaminated Channel Electron Multiplier Arrays", Harlow, F. E. and Hunter, W. R. 1972, Appl. Opt. 11, 2719.

1579 "The Extreme-Ultraviolet Spectrum of Fe XV in a Solar Flare", Cowan, R. D. and Widing, K. G. 1973, Astrophys. J. 180, 285.

1606 "The Increase in Transmittance of Unbacked Aluminum Filters Exposed to RF and DC Discharge in Oxygen", Hunter, W. R., Steele, G. N. and Gillette, R. B. 1973, Appl. Opt. 12, 2800.

1620 "A Preliminary Study of the Extreme Ultraviolet Spectroheliograms from Skylab", Tousey, R., Bartoe, J.-D. F., Bohlin, J. D., Brueckner, G. E., Purcell, J. D., Scherrer, V. E., Sheeley, N. R., Jr., Schumacher, R. J. and Van Hoosier, M. E. 1973, Solar Phys. 33, 265.

1642 "The Extreme Ultraviolet Spectrograph", Bartoe, J.-D. F., Brueckner, G. E., Purcell, J. D., and Tousey, R. 1974, SPIE 44, 153. (Invited)

1643 "Oxygen Densities at Altitudes Between 70 and 129 km", Brueckner, G. E., Bartoe, J.-D. F., Brown, C. M., Prinz, D. K., Tilford, S. G., and Van Hoosier, M. E., Space Research XVII, in press.

1647 "On the Fe XXIV Emission in the Solar Flare on June 15, 1973", Widing, K. G. and Cheng, C. C. 1974, Astrophys. J. Lett. 194, L111.

1650 "Structure of the Sun's Polar Cap in the Wavelengths 300-500 Å", Bohlin, J. D., Sheeley, N. R., Jr., and Tousey, R., Space Research XVII, in press.

1652 "Preliminary Results from the NRL/ATM Instruments from Skylab 2", Tousey, R., Bartoe, J.-D. F., Bohlin, J. D., Brueckner, G. E., Purcell, J. D., Scherrer, V. E., Schumacher, R. J., Sheeley, N. R., Jr., and Van Hoosier, M. E. 1974, in 'Coronal Disturbances', p. 491, ed. G. Newkirk, Jr., Reidel, Dordrecht. (Invited)

1655 "Implications of NRL/ATM Solar Flare Observations on Flare Theories", Cheng, C. C. and Spicer, D. S. 1975, in 'Solar Extreme UV, X, and γ Radiation', IAU/ COSPAR Symp. 68, ed. S. Kane.

1666 "Some Reflections on the Use of Conventional and Holographic Diffraction Gratings in the Vacuum Ultraviolet Spectral Region", Hunter, W. R. 1974, Proc. IV International Conf. on Vacuum-Ultraviolet Radiation Physics, p. 683.

1671 "Diffraction Gratings for the XUV - Conventional vs. Holographic", Hunter, W. R. 1974, Japanese J. of Spectroscopical Soc. 23, 37. (Invited)

1673 "Flare-Like Ultraviolet Spectra of Active Regions", Brueckner, G.E. 1975, in 'Solar Extreme UV, X, and γ Radiation', IAU/COSPAR Symp. 68, ed. S. Kane.

1675 "Ultraviolet Emission Line Profiles of Flares and Active Regions", Brueckner, G. E., 1975, in 'Solar Extreme UV, X, and γ Radiation', IAU/COSPAR Symp. 68, ed. S. Kane. (Invited)

1676 "The Fine Structure of the Solar Atmosphere in the Far Ultraviolet", Brueckner, G. E., and Bartoe, J.-D. F. 1974, Solar Phys. 38, 133.

1677 "Fe XXIV Emission in Solar Flares Observed with the NRL/ATM XUV Slitless Spectrograph", Widing, K. G., 1975, 'Solar Extreme UV, X, and γ Radiation', IAU/COSPAR Symp. 68, ed. S. Kane. (Invited)

1678 "Flares Observed by the NRL/ATM Spectrograph and Spectroheliogram During the Skylab Missions", Scherrer, V. E. and Tousey, R. 1975, Proc. International Conf. on 'X-rays in Space', Vol. II, 986, Univ. of Calgary.

1679 "XUV Observations of Coronal Magnetic Fields", Sheeley, N. R., Jr. Bohlin, J. D., Brueckner, G. E., Purcell, J. D., Scherrer, V. E., and Tousey, R. 1974, Solar Phys. 40, 103. (Invited)

1683 "Observations of the Hydrogen Ly-α (1216 Å) Emission Line of Comet Kohoutek (1973f) by the Skylab/ATM S082B Spectrograph", Keller, H. U., Bohlin, J. D., and Tousey, R. 1975, Proc. Comet Kohoutek Workshop, NASA SP-355, ed. G. A. Gary, in press. (Invited)

1684 "High Resolution Ly-α Observations of Comet Kohoutek by Skylab and Copernicus", Bohlin, J. D., Drake, J. F., Jenkins, E. B., and Keller, H. U., Proc. IAU Colloq. 25, in press.

1686 "XUV Observations of Coronal Magnetic Fields", Sheeley, N. R., Jr., Bohlin, J. D., Brueckner, G. E., Purcell, J. D., Scherrer, V. E., and Tousey, R. 1975, Solar Phys. 40, 103.

1687 "Observed Heights of EUV Lines Formed in the Transition Zone and Corona", Simon, G. W., Seagraves, P. H., Tousey, R., Purcell, J. D., Noyes, R. W. 1974, Solar Phys. 39, 121.

1689 "Ultraviolet Solar Identifications Based on Extended Absorption Series Observed in the Laboratory Spectra of Si I", Moore, C. E., Tousey, R., Sandlin, G. D., Brown, C. M., Ginter, M. L., and Tilford, S. G., Astrophys. and Sp. Sci., in press.

1690 "Ultraviolet Observations of Solar Flares from Skylab", Brueckner, G. E., in 'A Discussion on the Physics of the Solar Atmosphere', Phil. Trans. Roy. Soc. Lond., in press. (Invited)

1691 "Eruptive Prominences Recorded by the XUV Spectroheliograph on Skylab", Tousey, R., in 'A Discussion on the Physics of the Solar Atmosphere', Phil. Trans. Roy. Soc. Lond., in press. (Invited)

1695 "A Comparison of Spicules in the Hα and He II (304 Å) Lines", Moe, O. K., Engvold, E. and Beckers, J. 1975, Solar Phys. 40, 65.

1709 "The Reconnection of Magnetic Field Lines in the Solar Corona", Sheeley, N.R., Jr., Bohlin, J. D., Brueckner, G. E., Purcell, J. D., Scherrer, V. E., and Tousey, R. 1975, Astrophys. J. Lett. 196, L129.

1713 "Forbidden Lines of Highly Ionized Iron in Solar Flare Spectra", Doschek, G. A., Feldman, U., Dere, K. P., Sandlin, G. D., Van Hoosier, M. E., Brueckner, G. E., Purcell, J. D., and Tousey, R. 1975, Astrophys. J. Lett. 196, L83.

1715 "XUV Results from Skylab", Tousey, R. 1975, Proc. International Conf. on 'X-Rays in Space', Vol. I, 472, Univ. of Calgary. (Invited)

1716 "The XUV Sun as Observed by ATM S082", Tousey, R., Proc. of AIAA/AGU Space Science Conf. on 'Scientific Experiments of Project Skylab', in press.

1718 "Classification of Flares and Flare-Like Events Observed by the ATM XUV Spectroheliograph S082A and Spectrograph S082B During the Skylab Missions", Scherrer, V. E. and Tousey, R., Proc. of AIAA/AGU Space Science Conf. on 'Scientific Experiments of Project Skylab', in press.

1720 "The Stark Broadening Mechanism in an Unstable Plasma", Spicer, D. S. and Davis, J. 1975, Solar Phys., in press.

1721 "On the Fe XXIV Emission in the Solar Flare of 1973 June 15", Widing, K. G. and Cheng, C. C. 1974, Astrophys. J. Lett. 194, L115.

1724 "Fe XXIII 263 Å and Fe XXIV 255 Å Emission in Solar Flares", Widing, K. G. 1975, Astrophys. J. Lett. 197, L133.

1727 "A Newly Observed Solar Feature: Macro-Spicules in He II 304 Å", Bohlin, J. D., Vogel, S. N., Purcell, J. D., Sheeley, N. R., Jr., Tousey, R., and Van Hoosier, M. E. 1975, Astrophys. J. Lett. 197, L133.

1729 "The 1640.4 Å Hα Line of He II Observed from Skylab", Feldman, U., Doschek, G. A., Van Hoosier, M. E., and Tousey, R. 1975, Astrophys. J. Lett. 199, L67.

1733 "XUV Emission from Above the West Limb Near 20:00 U.T., January 17, 1974", Tousey, R., Astrophys. and Sp. Sci., in press. (Invited)

1745 "Spatial Distribution of XUV Emission in Solar Flares", Cheng, C.C. and Widing, K. G. 1975, Astrophys. J., in press.

1748 "The Interpretation of Ultraviolet Spectra", Moore-Sitterly, C. E., Proc. Twentieth Liege International Astrophysical Symp., in press. (Invited)

1760 "Absolute Solar Intensities 1750 Å-2100 Å and their Variations with Solar Activity", Brueckner, G. E., Bartoe, J.-D. F., Moe, O. K., Van Hoosier, M. E., Proc. 'Workshop on the Solar Constant and the Earth's Climate', in press. (Invited)

1762 "Selected Tables of Atomic Spectra, Atomic Energy Levels and Multiplet Tables OI", Moore-Sitterly, C. E., NSRDS-NBS 3, Sec. 7, in press.

1773 "Advances in X-Ray and EUV Spectroscopy of Solar Flares and Laboratory Plasmas", Doschek, G. A. 1975, Proc. International Conf. on 'X-Rays in Space', Vol. I, 306.

II. PROFESSIONAL PUBLICATIONS - SUBMITTED

1692 "High Resolution Ly α Observations of Comet Kohoutek Near Perihelion", Keller, H. U., Bohlin, J. D., and Tousey, R. Submitted to Astron. and Astrophys.

1749 "Coronal Changes Associated with a Disappearing Filament", Sheeley, N. R., Jr., Bohlin, J. D., Brueckner, G. E., Purcell, J. D., Scherrer, V. E., and Tousey R. Submitted to Solar Phys.

1765 "Limb Brightening Curves of XUV Transition Zone Lines in the Quiet Sun and in a Polar Coronal Hole Observed from Skylab", Doschek, G. A., Feldman, U., and Tousey, R. Submitted to Astrophys. J. Lett.

1766 "The Intensities and Profiles of XUV Transition Lines in a Quiet Sun Region Compared to a Polar Coronal Hole", Feldman, U., Doschek, G. A., and Tousey, R. Submitted to Astrophys. J. Lett.

III. ABSTRACTS

1509 "Absolute Intensity of the Continuum in the Ultraviolet Spectrum of the Sun Between 1650-1800 Å", Brueckner, G. E., Moe, O. K., and Pitz, E., BAAS 3, 260 (1971).

1510 "High Spectral and Spatial Resolution Ultraviolet Spectroscopy of the Sun in the Region 1170-1800 Å", Brueckner, G. E., BAAS 3, 259 (1971).

1529 "On the Classification of Some Highly Ionized Iron and Nickel Lines in the 200-400 Å Region of the Solar Spectrum", Widing, K. G. and Sandlin, G. D., Cowan, R. D., Sp. Sci. Rev. 13, 665 (1971).

1544 "Extreme Ultraviolet Spectroheliograms of a Solar Flare", Purcell, J. D. and Tousey, R., BAAS 3, 448 (1971).

1545 "Preliminary Results of Identifications in the XUV Spectrum of a Solar Flare", Purcell, J. D., Tousey, R., and Widing, K. G., BAAS 3, 448 (1971).

1565 "The Coronal Origin of a Solar Flare", Brueckner, G. E., BAAS 4, 378 (1972).

1572 "A Recalibration of Spectral Radiance of Mercury and Deuterium Arc Standard Lamps in the Near UV", Bartoe, J.-D. F. and Ott, W. R., J. Opt. Soc. Am. 6, 1372 (1972).

1623 "The 1175 Å to 1900 Å Ultraviolet Spectrum of Solar Flares", Brueckner, G. E., Bohlin, J. D., Moe, O. K., Nicolas, K. R., Purcell, J. D., Scherrer, V. E., Sheeley, N. R., Jr., and Tousey, R., BAAS 6, 285 (1974).

1624 "Electron Density from Line Ratios in the XUV Spectrum of a Solar Flare", Widing, K. G., Purcell, J. D., and Tousey R., BAAS 6, 297 (1974).

1625 "The Screw Pinch and the Solar Flare", Spicer, D. S. and Cheng, C. C., BAAS 6, 294 (1974).

1626 "A Preliminary Study of Coronal Structures by Means of Time-Lapse Photography", Sheeley, N. R., Jr., Bohlin, J. D., Brueckner, G. E., Purcell, J. D., Scherrer, V. E., and Tousey, R., BAAS 6, 294 (1974).

1628 "Rocket Spectroheliogram Observations of the Heights of Formation and Sizes of Bright Features in the Transition Zone", Simon, G. W., Seagraves, P. H., and Tousey, R., BAAS 6, 292 (1974).

1629 "Cinematographic Observations for ATM and Their Comparison with Some ATM Results", Zirin, H., Holt, J., Brueckner, G. E., Bohlin, J. D., Purcell, J. D., Scherrer, V. E., Sheeley, N. R., Jr., and Tousey, R., BAAS 6, 298 (1974).

1637 "Studies of Atmospheric Extinction from Skylab", Brown, C. M., Tousey, R., Tilford, S. G., and Prinz, D. K., EOS 55, 371 (1974).

1640 "Coronal Extreme Ultraviolet Spectroheliograph and Chromospheric Extreme Ultraviolet Spectrograph", Tousey., BAAS 6, 297 (1974).

1641 "The Extreme Ultraviolet Spectroheliograph and the Extreme Ultraviolet TV Monitor", Tousey, R., Bartoe, J.-D. F., Brueckner, G. E., and Purcell, J. D., SPIE, 'Instrumentation in Astronomy - II'.

1642 "The Extreme Ultraviolet Spectrograph", Bartoe, J.-D. F., Brueckner, G. E., Purcell, J. D., and Tousey, R., SPIE, 'Instrumentation in Astronomy - II'.

1657 "Skylab Observation of the White Light Corona and the He II 304 Å Chromosphere During the Eruptive Prominence Event of August 21, 1973", Bohlin, J. D., Brueckner, G. E., Purcell, J. D., Scherrer, V. E., Sheeley, N. R., Jr., Tousey, R., Poland, A. I., EOS 55, 409 (1974).

"The Eruptive Prominence of August 21, 1973, Observed from Skylab in the White Light Corona and in the He II 304 Å Chromosphere", Poland, A. I., Bohlin, J. D., Brueckner, G. E., Purcell, J. D., Scherrer, V. E., Sheeley, N. R., Jr., and Tousey, R., BAAS 6 219 (1974).

1658 "Preliminary Results from the Extreme Ultraviolet Spectroheliograph and Ultraviolet Spectrograph on ATM", Tousey, R., EOS 55, 408 (1974).

1668 "Skylab Observations of the Sun (170-630 Å) with the NRL Objective Grating Spectroheliograph", Widing, K. G., J. Opt. Soc. Am. 64, 1375 (1974).

1674 "Spectrophotometry of the Solar Ultraviolet Line Spectrum with the NRL Spectrograph onboard Skylab", Brueckner, G. E., J. Opt. Soc. Am. 64, 1375 (1974).

1685 "ATM Observations on the XUV Emission from Flares", Brueckner, G. E., Astrophys. and Sp. Sci., in press.

Ibid., Stanford Univ. Inst. for Plasma Res. Report No. 594 (1974).

"Evidence for Non-Hydrostatic Equilibrium Conditions in the Transition Region", Brueckner, G. E., Stanford Univ. Inst. for Plasma Res. Report No. 594 (1974).

1696 "A Catalog and Classification of Flares and Flare-Like Events Observed by the ATM XUV Spectrograph S082A and Spectroheliograph S082B", Scherrer, V. E., Tousey, R., and Sandlin, G. D., BAAS 7, 356 (1975).

1697 "Polar Plumes in XUV Emission-Line Corona", Bohlin, J. D., Purcell, J. D., Sheeley, N. R., Jr., and Tousey, R., BAAS 7, 356 (1975).

1698 "Macro-Spicules in He II 304 Å Over the Sun's Polar Cap", Bohlin, J. D., Vogel, S. N., Purcell, J. D., Sheeley, N. R., Jr., Tousey, R., and Van Hoosier, M. E., BAAS 7, 354 (1975).

1699 "Flare Mechanisms Based on the Current Limitation Concept", Spicer, D. S., BAAS 7, 352 (1975).

1700 "Absolute Solar UV Intensities 1680 Å to 2100 Å", Moe, O. K., Brueckner, G. E., Bartoe, J.-D. F., and Van Hoosier, M. E., BAAS 7, 360 (1975).

1701 "On the XUV Emissions in Solar Flares Observed with the ATM/NRL Spectroheliograph", Cheng, C. C. and Widing, K. G., BAAS 7, 356 (1975).

1703 "Observations from Skylab of the Density Dependent C III Multiplet at 1175 Å in Active and Quiet Regions and Above the Limb", Nicolas, K. and Brueckner, G. E., BAAS 7, 353 (1975).

1705 "The High-Energy Limb Event of January 17, 1974", Tousey, R., Bohlin, J. D., Moe, O. K., Purcell, J. D., and Sheeley, N. R., Jr., BAAS 7, 348 (1975).

1706 "Interpreting XUV Spectroheliograms in Terms of Coronal Magnetic Field Structures", Sheeley, N. R., Jr., Bohlin, J. D., Brueckner, G. E., Purcell, J. D., Scherrer, V. E., and Tousey, R., BAAS 7, 346 (1975).

1707 "Line Profiles of the Fe XXIV Emission at 192 Å and 255 Å in Solar Flares", Brueckner, G. E., Moe, O. K., and Van Hoosier, M. E., BAAS 7, 356 (1975).

1712 "The Superheating Instability as a Trigger for Solar Flares", Tidman, D. A., Spicer, D. S., and Davis, J., BAAS 7, 352 (1975).

1714 "Forbidden Lines of Highly Ionized Iron in Solar Flare Spectra", Doschek, G. A., Sandlin, G. D., Brueckner, G. E., Van Hoosier, M. E., and Tousey, R., Astrophys. and Sp. Sci., in press.

1716 "The XUV Sun as Observed by ATM S082", Tousey, R., AIAA Bulletin 11, 344 (1974).

1718 "Classification of Flares and Flare-Like Events Observed by the ATM XUV Spectroheliograph S082A and Spectrograph S082B During the Skylab Missions", Scherrer, V. E. and Tousey, R., AIAA Bulletin 11, 345 (1974).

1726 "Structure and Temperature of Solar Flare Plasma", Scherrer, V. E. and Sandlin, G. D., BAPS 20, 659 (1974).

1750 "A Resistive Screw Instability Model of a Solar Flare", Spicer, D. S., BAAS, in press.

1751 "A Time Dependent Study of Conductive Heat Flow in a Flaring Arch", Kepple, P. C. and Spicer, D. S., BAAS, in press.

1752 "The Sun's Polar Caps as Coronal Holes; Their Sizes, Evolution, and Phenomenology During the Skylab Mission", Bohlin, J. D., Rubenstein, D. M., and Sheeley, N. R., Jr., BAAS, in press.

1753 "Energy Release and Thermal Structure in Solar Flares" Cheng, C. C. and Widing, K. G., BAAS, in press.

1754 "X-Ray Event of August 13-15, 1973", Scherrer, V. E., Sandlin, G. D., Sheeley, N. R., Jr., and Tousey, R., BAAS, in press.

1756 "Skylab/ATM Observations of Transient Events Having the GRF X-Ray and Microwave Character", Sheeley, N. R., Jr., Bohlin, J. D., Scherrer, V. E., and Tousey, R., BAAS, in press.

1757 "Measured Variation of the XUV Line Widths and Intensities Near the Solar Limb", Moe, O. K. and Nicolas, K. R., BAAS, in press.

1758 "Evolution of XUV Plasmas in Solar Flares", Widing, K. G. and Cheng, C. C., BAAS, in press.

1768 "Solar Flare Collision Excitation Rate Coefficients", Tousey, R., Kepple, P. C., and Davis, J. BAAS, in press.

1769 "Plasma Heating and Flare X-Rays", Davis, J., Kepple, P., Strickland, D., and Brueckner, G., BAAS, in press.

1770 "Hydrodynamics of Electron Beam Deposition in Solar Flares", Bloomberg, H., Kepple, P. C., Davis, J., Boris, J., Brueckner, G., BAAS, in press.

1771 "Results from the NRL XUV Experiment on Skylab", Tousey, R., J. Opt. Soc. Am. 64, 523 (1974).

1772 "Maximum Efficiency of Ruled Concave Diffraction Gratings in the Ultraviolet", Mikes, T. L., J. Opt. Soc. Am. 64, 1371 (1974).

1776 "Time Dependent Ionization Equilibrium and Line Emission from Ionized Iron Under Flare-Like Conditions", Kepple, P. and Davis, J., EOS 56, 1183 (1974).

1777 "Transient Line Emission from Ionized Iron Under Flare-Like Conditions", Davis, J., Kepple, P., and Tousey, R., BAAS 7, 357 (1975).

1778 "Absolute Calibrated Solar UV Intensities 1700 - 2100 Å", Moe, O. K., J. Opt. Soc. 64, 1375 (1974).

1779 "The Source of Material Comprising a Mass Ejection Coronal Transient", Hildner, E., Gosling, J. T., Hansen, R. T., and Bohlin, J. D., BAAS, in press.

IV. PROFESSIONAL TALKS - INVITED

"The ATM Project", Tousey, R., Symp. on 'Calibration Methods in the UV and X-Ray Regions of the Spectrum', Institut fur extraterrestrische Physik, Max Planck Institut fur Physik und Astrophysik, Munich, Germany, 27-30 May 1968.

1514 "Identifications in the Solar XUV Spectrum", Tousey, R., 14th Gen. Assembly IAU, Commission 44, University of Sussex, Brighton, England, 20 August 1970.

"Solar Astronomy, Some Highlights of the Past Year", Tousey, R., 14th Gen. Assembly IAU, IAU Commission 44, University of Sussex, Brighton, England, 20 August 1970.

1515 "Survey of New Solar Results", Tousey, R., IAU Symp. 41, 'New Techniques in Space Astronomy', Munich, Germany, 10-14 August 1970.

1518 "Solar Spectroscopy from Space Vehicles", Tousey, R., Tenth National Meeting of the Society for Applied Spectroscopy, St. Louis, Missouri, 18-22 October 1971.

1522 "High Angular Observations from Rockets: Solar XUV Observations", Tousey, R., COSPAR XII, Seattle, Washington, 17 June - 2 July 1971.

1565 "The Coronal Origin of a Solar Flare", Brueckner, G. E., COSPAR XV, Madrid, Spain, 10-24 May 1972.

Ibid., AAS, Solar Phys. Div., University of Maryland, College Park, Maryland, 4-6 April 1972.

1641 "The Extreme Ultraviolet Spectroheliograph and the Extreme Ultraviolet TV Monitor", Tousey, R., Bartoe, J.-D. F., Brueckner, G. E., and Purcell, J. D., Soc. Photo-Optical Instr. Eng., 'Instrumentation in Astronomy - II', Tucson, Arizona, 4-6 March 1974.

1642 "The Extreme Ultraviolet Spectrograph", Bartoe, J.-D. F., Brueckner, G. E., Purcell, J. D., and Tousey, R., Soc. Photo-Optical Instr. Eng., 'Instrumentation in Astronomy - II', Tucson, Arizona, 4-6 March 1974.

1651 "The Sun as Observed by the ATM XUV Spectroheliograph and Spectrograph, S082A and B", Tousey, R., COSPAR XVII, Sao Paulo, Brazil, 25 June - 1 July 1974.

1652 "Preliminary Results from the NRL/ATM Instruments from Skylab 2", Tousey, R., Bartoe, J.-D. F., Bohlin, J. D., Brueckner, G. E., Purcell, J. D., Scherrer, V. E., Schumacher, R. J., Sheeley, N. R., Jr., and Van Hoosier, M. E., IAU Symp. 57, 'Coronal Disturbances', Surfers Paradise, Queensland, Australia, 19 August - 11 September 1973.

1658 "Preliminary Results from the Extreme Ultraviolet Spectroheliograph and Ultraviolet Spectrograph on ATM", Tousey, R., AGU, 55th Annual Meeting, Washington, D. C., 8-12 April 1974.

"Results from the NRL Experiments on Skylab", Tousey, R., Opt. Soc. Am., Washington, D. C., 22 April 1974.

1662 "Some NRL/ATM Observations of a Coronal Hole at the Solar Limb", Sheeley, N. R., Jr., 3rd Solar Wind Conf., Asilomar, California, 25-29 March 1974.

1668 "Skylab Observations of the Sun (170-630 Å) with the NRL Objective Grating Spectroheliograph", Widing, K. G., Opt. Soc. Am., Houston, Texas, 15-18 October 1974.

1671 "Diffraction Gratings for the XUV - Conventional vs. Holographic" Hunter, W. R., Symp. on 'Diffraction Gratings and Grating Instruments', Tokyo, Japan, 31 August 1974.

1675 "Ultraviolet Emission Line Profiles of Flares and Active Regions", Brueckner, G. E., IAU/COSPAR Symp. 68, 'Solar Extreme UV, X and γ Radiation', Buenos Aires, Argentina, 11-14 June 1974.

1677 "Fe XXIV Emission in Solar Flares Observed with the NRL/ATM XUV Slitless Spectrograph", Widing, K. G., IAU/COSPAR Symp. 68, 'Solar Extreme UV, X and γ Radiation', Buenos Aires, Argentina, 11-14 June 1974.

1679 "XUV Observations of Coronal Magnetic Fields", Sheeley, N. R., Jr., Bohlin, J. D., Brueckner, G. E., Purcell, J. D., Scherrer, V. E., and Tousey, R., Conf. on 'Flare-Related Magnetic Field Dynamics', Boulder, Colorado, 23 September 1974.

1683 "Observations of the Hydrogen Ly-α (1216 Å) Emission Line of Comet Kohoutek (1973f) by the Skylab/ATM S082B Spectrograph", Keller, H. U., Bohlin, J. D., and Tousey, R., Comet Kohoutek Workshop, MSFC, Huntsville, Alabama, 13-14 June 1974.

1685 "ATM Observations on the XUV Emission from Flares", Brueckner, G. E., IAU Colloq. 27, 'Fourth Conf. on Ultraviolet and X-Ray Spectroscopy of Astrophysical and Laboratory Plasmas', Harvard University, Cambridge, Massachusetts, 9-11 September 1974.

Ibid., 'Solar Physics - Plasma Physics Workshop', Stanford University, Stanford, California, 17-20 September 1974.

"Evidence for Non-Hydrostatic Equilibrium Conditions in the Transition Region", Brueckner, G. E., 'Solar Physics - Plasma Physics Workshop', Stanford University, Stanford, California, 17-20 September 1974.

1690 "Ultraviolet Observations of Solar Flares from Skylab", Brueckner, G. E., Royal Society Discussion Meeting 'The Physics of the Solar Atmosphere', London, England, 14-15 January 1975.

1691 "Eruptive Prominences Recorded by the XUV Spectroheliograph on Skylab", Tousey, R., Royal Society Discussion Meeting, 'The Physics of the Solar Atmosphere', London, England, 14-15 January 1975.

1715 "XUV Results from Skylab", Tousey, R., International Conf. on 'X-Rays in Space', University of Calgary, Calgary, Alberta, Canada, 14-21 August 1974.

1733 "XUV Emission from Above the West Limb Near 20:00 U.T., January 17, 1974", Tousey, R., IAU Colloq. 27, 'Fourth Conf. on Ultraviolet and X-Ray Spectroscopy of Astrophysical and Laboratory Plasmas', Cambridge, Massachusetts, 9-11 September 1974.

1734 "A Review of Skylab/ATM Observations and Analyses of Coronal Transients", Gosling, J. T., Bohlin, J. D., Krieger, A. S., Schmahl, E. J., Tandberg-Hanssen, E., COSPAR XVIII, Varna, Bulgaria, 29 May - 7 June 1975.

1748 "The Interpretation of Ultraviolet Solar Spectra", Moore-Sitterly, C. E., Twentieth Liege International Astrophysical Symp., Liege, Belgium, 17-20 June 1975.

1760 "Absolute Solar Intensities 1750 Å - 2100 Å and Their Variations with Solar Activity", Brueckner, G. E., Bartoe, J.-D. F., Moe, O. K., Van Hoosier, M. E., 'Workshop on the Solar Constant and the Earth's Climate', Big Bear Solar Observatory, Big Bear City, California, 19-21 May 1975.

1774 "First Results from Skylab", Tousey, R., AAS, Tucson, Arizona, 2-6 December 1973.

1778 "Absolute Calibrated Solar UV Intensities 1700 to 2100 Å", Moe, O. K., Opt. Soc. Am., Houston, Texas, 15-18 October 1974.

V. PROFESSIONAL TALKS - CONTRIBUTED

1420 "Some Recent XUV Spectroheliograms and Heliograms from Rockets", Purcell, J. D., Bartoe, J.-D. F., Snider, C. B., and Tousey, R., Second International Conf. on 'Vacuum Ultraviolet and X-Ray Spectroscopy of Laboratory and Astrophysical Plasmas', University of Maryland, 24-28 March 1968.

1469 "Radiation Light Sources for Stellar Telescope Calibration from 700 Å to 7000 Å", Hunter, W. R., Workshop on Optical Telescope Technology, MSFC, Huntsville, Alabama, May 1969.

1471 "Some Experiments on the Corona Surrounding a Spacecraft - Past, Planned and Proposed", Tousey, R., Opt. Soc. Am. Symp. on 'Optical Contamination in Space', Aspen, Colorado, 13-15 August 1969.

1479 "A Photographic Spectrum of a Flare in the XUV", Purcell, J. D. and Tousey, R., International Symp. on Solar Terrestrial Physics, Leningrad, U.S.S.R., 13 May 1970.

1481 "Observations of the Sun in the Extreme Ultraviolet", Tousey, R., Meeting of the Royal Society, London, England, 21-22 April 1970.

1499 "Observation of Stark-Effect in a Far UV Flare Spectrum", Brueckner, G. E., 14th Gen. Assembly IAU, University of Sussex, Brighton, England, 18-27 August 1970.

1509 "Absolute Intensity of the Continuum in the Ultraviolet Spectrum of the Sun Between 1650-1800 Å", Brueckner, G. E., Moe, O. K., Pitz, E., AAS, Solar Phys. Div., Huntsville, Alabama, 17 November 1970.

1510 "High Spectral and Spatial Resolution Ultraviolet Spectroscopy of the Sun in the Region 1170-1800 Å", Brueckner, G. E., AAS, Solar Phys. Div., Huntsville, Alabama, 17 November 1970.

1529 "On the Classification of Some Highly Ionized Iron and Nickel Lines in the 200-400 Å Region of the Solar Spectrum", Widing, K. G., Sandlin, G. D., and Cowan, R. D., Third Symp. on 'Ultraviolet and X-Ray Spectroscopy of Astrophysical and Laboratory Plasmas', Utrecht, The Netherlands, 24-26 August 1971.

1536 "XUV Television of a Solar Image from a Rocket", Tousey, R., Symp. on 'The Processing of Telescopic Images', Laval University, Quebec, Quebec, Canada, 1-2 October 1971.

1538 "Possibilities for Measuring Atmospheric Extinction and Absorption with the ATM Solar Experiments in Skylab", Tousey, R., Informal Conf. on 'The Uses of Astronomy in the Study of Air Pollution' Project, Seattle, Washington, 18 August 1971.

1544 "Extreme Ultraviolet Spectroheliograms of a Solar Flare", Purcell, J. D. and Tousey, R., AAS, 136th meeting, San Juan, Puerto Rico, 6-8 December 1971.

1545 "Preliminary Results of Identifications in the XUV Spectrum of a Solar Flare", Purcell, J. D., Tousey, R., and Widing, K. G., AAS, San Juan, Puerto Rico, 6-8 December 1971.

1572 "A Recalibration of Sectral Radiance of Mercury and Deuterium Arc Standard Lamps in the Near UV", Bartoe, J.-D. F. and Ott, W. R., Opt. Soc. Am., San Francisco, California, 17-20 October 1972.

1606 "The Increase in Transmittance of Unbacked Aluminum Filters Exposed to RF and DC Discharge in Oxygen", Hunter, W. R., Steele, G. N., and Gillette, R. B., Opt. Soc. Am., Rochester, New York, 9-12 October 1973.

1623 "The 1175 Å to 1900 Å Ultraviolet Spectrum of Solar Flares", Brueckner, G. E., Bohlin, J. D., Moe, O. K., Nicolas, K. R., Purcell, J. D., Scherrer, V. E. , Sheeley, N. R., Jr., and Tousey, R., AAS, Solar Phys. Div., Honolulu, Hawaii, 9-11 January 1974.

1624 "Electron Density from Line Ratios in the XUV Spectrum of a Solar Flare", Widing, K. G., Purcell, J. D., and Tousey, R., AAS, Solar Phys. Div., Honolulu, Hawaii, 9-11 January 1974.

1625 "The Screw Pinch and the Solar Flare", Spicer, D. S. and Cheng, C. C., AAS, Solar Phys. Div., 9-11 January 1974.

1626 "A Preliminary Study of Coronal Structures by Means of Time-Lapse Photography", Sheeley, N. R., Jr., Bohlin, J. D., Brueckner, G. E., Purcell, J. D., Scherrer, V. E., and Tousey, R., AAS, Solar Phys. Div., 9-11 January 1974.

1628 "Rocket Spectroheliogram Observations of the Heights of Formation and Sizes of Bright Features in the Transition Zone", Simon, G. W., Seagraves, P. H., and Tousey, R., AAS, Solar Phys. Div., Honolulu, Hawaii, 9-11 January 1974.

1629 "Cinematographic Observations for ATM and their Comparison with some ATM Results", Zirin, H., Holt, J., Brueckner, G. E., Bohlin, J. D., Purcell, J. D., Scherrer, V. E., Sheeley, N. R., Jr., and Tousey, R., AAS, Solar Phys. Div., Honolulu, Hawaii, 9-11 January 1974.

1637 "Studies of Atmospheric Extinction from Skylab", Brown, C. M., Tousey, R., Tilford, S. G., and Prinz, D. K., AGU, 55th Annual Meeting, Washington, D. C., 8-12 April 1974.

1640 "Coronal Extreme Ultraviolet Spectroheliograph and Chromospheric Extreme Ultraviolet Spectrograph", Tousey, R., AAS, Solar Phys. Div., Honolulu, Hawaii, 9-11 January 1974.

1643 "Oxygen Densities at Altitudes Between 70 and 129 km", Brueckner, G. E., Bartoe, J.-D. F., Brown, C. M., Prinz, D. K., Tilford, S. G., and Van Hoosier, M. E., COSPAR XVII, Sao Paulo, Brazil, 25 June - 1 July 1974.

1646 "Ultraviolet Emission Line Profiles of Flares and Flare-Like Events Observed from Skylab", Brueckner, G. E., Moe, O. K., and Nicolas, K. R., COSPAR XVII,, Sao Paulo, Brazil, 25 June - 1 July 1974.

1647 "On the Fe XXIV Emission in the Solar Flare of June 15, 1973", Widing, K. G. and Cheng, C. C., COSPAR XVII, Sao Paulo, Brazil, 25 June - 1 July 1974.

1650 "Structure of the Sun's Polar Cap in the Wavelengths 300-500 Å", Bohlin, J. D., Sheeley, N. R., Jr., and Tousey, R., COSPAR XVII, Sao Paulo, Brazil, 25 June - 1 July 1974.

1655 "Implications of NRL/ATM Solar Flare Observations on Flare Theories", Cheng, C. C. and Spicer, D. S., IAU/COSPAR Symp. 68, 'Solar Extreme UV, X and Radiation', Buenos Aires, Argentina, 11-14 June 1974.

1657 "Skylab Observation of the White Light Corona and the He II 304 Å Chromosphere During the Eruptive Prominence Event of August 21, 1973", Bohlin, J. D., Brueckner, G. E., Purcell, J. D., Scherrer, V. E., Sheeley, N. R., Jr., Tousey, R., and Poland, A. I., AGU, 55th Annual Meeting, Washington, D. C., 8-12 April 1974.

"The Eruptive Prominence of August 21, 1973, Observed from Skylab in the White Light Corona and in the He II 304 Å Chromosphere", Poland, A. I., Bohlin, J. D., Brueckner, G. E., Purcell, J. D., Scherrer, V. E., Sheeley, N. R., Jr., and Tousey, R., AAS, Lincoln, Nebraska, 26-29 March 1974.

1666 "Some Reflections on the Use of Conventional and Holographic Diffraction Gratings in the Vacuum Ultraviolet Spectral Region", Hunter, W. R., IV International Conf. on Vacuum-Ultraviolet Radiation Physics, Hamburg, Germany, 22-26 July 1974.

1673 "Flare-Like Ultraviolet Spectra of Active Regions", Brueckner, G. E., IAU/COSPAR Symp. 68, 'Solar Extreme UV, X and γ Radiation', Buenos Aires, Argentina, 11-14 June 1974.

1678 "Flares Observed by the NRL/ATM Spectrograph and Spectroheliograph During the Skylab Missions", Scherrer, V. E. and Tousey, R., International Conf on 'X-Rays in Space', University of Calgary, Calgary, Alberta, Canada, 14-21 August 1974.

1681 "The Impact of ATM/NRL Flare Data on Flare Theory", Spicer, D. S., Cheng, C. C., Widing, K. G., and Tousey, R., Second European Conf. on Cosmic Plasma Physics, Culham, England, 1 July 1974.

"Diffraction Gratings in Space Research - Problems and Accomplishments", Hunter, W. R., Informal meeting on diffraction gratings, Kyoto, Japan, 6 September 1974.

1684 "High Resolution Ly-α Observations of Comet Kohoutek by Skylab and Copernicus", Bohlin, J. D., Drake, J. F., Jenkins, E. B., and Keller, H. U., IAU Colloq. 25, Goddard Space Flight Center, Greenbelt, Maryland, 28 October - 1 November 1974.

1689 "Ultraviolet Solar Identifications Based on Extended Absorption Series Observed in the Laboratory Spectra of Si I", Moore, C. E., Tousey, R., Sandlin, G. D., Brown, C. M., Ginter, M. L., and Tilford, S. G., IAU Colloq. 27, 'Fourth Conf. on Ultraviolet and X-Ray Spectroscopy of Astrophysical and Laboratory Plasmas', Harvard University, Cambridge, Massachusetts, 9-11 September 1974.

1696 "A Catalog and Classification of Flares and Flare-Like Events Observed by the ATM XUV Spectrograph S082A and Spectroheliograph S082B", Scherrer, V. E., Tousey, R., and Sandlin, G. D., AAS, Solar Phys. Div., Boulder, Colorado, 20-22 January 1975.

1697 "Polar Plumes in XUV Emission-Line Corona", Bohlin, J. D., Purcell, J. D., Sheeley, N. R., Jr., and Tousey, R., AAS, Solar Phys. Div., Boulder, Colorado, 20-22 January 1975.

1698 "Macro-Spicules in He II 304 Å Over the Sun's Polar Cap", Bohlin, J. D., Vogel, S. N., Purcell, J. D., Sheeley, N. R., Jr., Tousey, R., and Van Hoosier, M. E., AAS, Solar Phys. Div., Boulder, Colorado, 20-22 January 1975.

1699 "Flare Mechanisms Based on the Current Limitation Concept", Spicer, D. S., AAS, Solar Phys. Div., Boulder, Colorado, 20-22 January 1975.

1700 "Absolute Solar UV Intensities 1680 Å to 2100 Å", Moe, O. K., Brueckner, G. E., Bartoe, J.-D. F., and Van Hoosier, M. E., AAS, Solar Phys. Div., Boulder, Colorado, 20-22 January 1975.

1701 "On the XUV Emissions in Solar Flares Observed with the ATM/NRL Spectroheliograph", Cheng, C. C. and Widing, K. G., AAS, Solar Phys. Div., Boulder, Colorado, 20-22 January 1975.

1703 "Observations from Skylab of the Density Dependent C III Multiplet at 1175 Å in Active and Quiet Regions and Above the Limb", Nicolas, K. and Brueckner, G. E., AAS, Solar Phys. Div., Boulder, Colorado, 20-22 January 1975.

1705 "The High-Energy Limb Event of January 17, 1974", Tousey, R., Bohlin, J. D., Moe, O. K., Purcell, J. D., and Sheeley, N. R., Jr., AAS, Solar Phys. Div., Boulder, Colorado, 20-22 January 1975.

1706 "Interpreting XUV Spectroheliograms in Terms of Coronal Magnetic Field Structures", Sheeley, N. R., Jr., Bohlin, J. D., Brueckner, G. E., Purcell, J. D., Scherrer, V. E., and Tousey, R., AAS, Solar Phys. Div., Boulder, Colorado, 20-22 January 1975.

1707 "Line Profiles of the Fe XXIV Emission at 192 Å and 255 Å in Solar Flares", Brueckner, G. E., Moe, O. K., and Van Hoosier, M. E., AAS, Solar Phys. Div., Boulder, Colorado, 20-22 January 1975.

1712 "The Super Heating Instability as a Trigger for Solar Flares", Tidman, D. A., Spicer, D. S., and Davis, J., AAS, Solar Phys. Div., Boulder, Colorado, 20-22 January 1975.

1714 "Forbidden Lines of Highly Ionized Iron in Solar Flare Spectra", Doschek, G. A., Sandlin, G. D., Brueckner, G. E., Van Hoosier, M. E., and Tousey, R., IAU Colloq. 27, 'Fourth Conf. on Ultraviolet and X-Ray Spectroscopy of Astrophysical and Laboratory Plasma', Harvard University, Cambridge, Massachusetts, 9-11 September 1974.

1716 "The XUV Sun as Observed by ATM S082", Tousey, R., AIAA/AGU Space Science Conf. on 'Scientific Experiments of Project Skylab', MSFC, Huntsville, Alabama, 30 October- 1 November 1974.

1718 "Classification of Flares and Flare-Like Events Observed by the ATM XUV Spectroheliograph S082A and Spectrograph S082B During the Skylab Missions", Scherrer, V. E. and Tousey, R., AIAA/AGU Space Science Conf. on 'Scientific Experiments of Project Skylab', MSFC, Huntsville, Alabama, 30 October-1 November 1974.

1726 "Structure and Temperature of Solar Flare Plasma", Scherrer, V. E. and Sandlin, G. D., Am. Phys. Soc., Washington, D. C., 28 April - 1 May 1975.

1731 "The Character and Temperature of a Coronal Transient: I. The Event of 25-27 August 1973", Bohlin, J. D., Hildner, E., and Hansen, R. T., COSPAR XVIII, Varna, Bulgaria, 29 May - 7 June 1975.

1738 "Experience with Schumann Type UV Film on Skylab", Van Hoosier, M. E., Bartoe, J.-D. F., Brueckner, G. E., Moe, O. K., Nicolas, K. R., and Tousey, R., Topical Meeting on 'Imaging in Astronomy', Harvard University, Cambridge, Massachusetts, 18-20 June 1975.

1739 "Limitations of Imaging Capabilities of Schumann Type UV Film", Bartoe, J.-D., Brueckner, G. E., and Van Hoosier, M. E., Topical Meeting on 'Imaging in Astronomy', Harvard University, Cambridge, Massachusetts, 18-20 June 1975.

1750 "A Resistive Screw Instability Model of a Solar Flare", Spicer, D. S., AAS, San Diego, California, 17-20 August 1975.

1751 "A Time Dependent Study of Conductive Heat Flow in a Flaring Arch", Kepple, P. C. and Spicer, D. S., AAS, San Diego, California, 17-20 August 1975.

1752 "The Sun's Polar Caps as Coronal Holes; Their Sizes, Evolution, and Phenomenology During the Skylab Mission", Bohlin, J. D., Rubenstein, D. M., and Sheeley, N. R., Jr., AAS, San Diego, California, 17-20 August 1975.

1753 "Energy Release and Thermal Structure in Solar Flares", Cheng, C. C. and Widing, K. G., AAS, San Diego, California, 17-20 August 1975.

1754 "X-Ray Event of August 13-15, 1973", Scherrer, V. E., Sandlin, G. D., Sheeley, N. R., Jr., and Tousey, R., AAS, San Diego, California, 17-20 August 1975.

1756 "Skylab/ATM Observatins of Transient Events Having the GRF X-Ray and Microwave Character", Sheeley, N. R., Jr., Bohlin, J. D., Scherrer, V. E., and Tousey, R., AAS, San Diego, California, 17-20 August 1975.

1757 "Measured Variation of the XUV Line Widths and Intensities Near the Solar Limb", Moe, O. K. and Nicolas, K. R., AAS, San Diego, California, 17-20 August 1975.

1758 ""Evolution of XUV Plasmas in Solar Flares", Widing, K. G. and Cheng, C.C., AAS, San Diego, California, 17-20 August 1975.

1768 "Solar Flare Collisional Excitation Rate Coefficients", Tousey, R., Kepple, P. C., and Davis, J., AAS, San Diego, California, 17-20 August 1975.

1769 "Plasma Heating and Flare X-Rays", Davis, J., Kepple, P., Strickland, D., and Brueckner, G., AAS, San Diego, California, 17-20 August 1975.

1770 "Hydrodynamics of Electron Beam Deposition in Solar Flares", Bloomberg, H., Kepple, P. C., Davis, J., Boris, J. and Brueckner, G., AAS, San Diego, California, 17-20 August 1975.

1771 "Results from the NRL XUV Experiments on Skylab", Tousey, R., Opt. Soc. Am., Washington, D. C., 21-25 April 1974.

1772 "Maximum Efficiency of Ruled Concave Diffraction Gratings in the Ultraviolet", Mikes, T. L., Opt. Soc. Am., Houston, Texas, 15-18 October 1974.

1776 "Time Dependent Ionization Equilibrium and Line Emission from Ionized Iron Under Flare-Like Conditions", Kepple, P. and Davis, J., AGU, San Francisco, California, December 1974.

1777 "Transient Line Emission from Ionized Iron Under Flare-Like Conditions", Davis, J., Kepple, P., and Tousey, R., AAS, Solar Phys. Div., Boulder, Colorado, 20-22 January 1975.

1779 "The Source of Material Comprising a Mass Ejection Coronal Transient", Hildner, E., Gosling, J. T., Hansen, R. T., and Bohlin, J. D., AAS, San Diego, California, 17-20 August 1975.

VI. COLLOQUIA

1465 "Apollo Telescope Mount Project", Winter, T. C., National Bureau of Standards, Washington, D. C., 27 February 1969.

1635 "The Sun in Lyman-Alpha", Prinz, D. K., National Capitol Section of the Amateur Astronomers of America, 2 February 1974.

1661 "NRL/ATM Observations with the XUV Spectroheliograph", Sheeley, N. R., Jr., Sacramento Peak Observatory, Sunspot, New Mexico, 15 March 1974.

1708 "Observations of the Sun in XUV with ATM", Tousey, R., Goddard Space Flight Center, Greenbelt, Maryland, 6 December 1974.

"Observations of the Sun in XUV with ATM", Tousey, R., University of Michigan, Ann Arbor, Michigan, 12 February 1975.

1728 "Preliminary Results from the NRL XUV Spectroheliograph and Spectrograph", Bohlin, J. D., University of Maryland, College Park, Maryland, 26 February 1975.

1737 "Behavior of Coronal Magnetic Fields as Deduced from Skylab Observations", Sheeley, N. R., Jr. High Altitude Observatory, Boulder, Colorado, 14 March 1975.

1757 "Macrospicules, Polar Plumes, Coronal Holes, and Other Assorted Phenomena of the Sun's Polar Cap", Bohlin, J. D., National Capital Astronomers, Washington, D.C., 6 September 1975.

VII. OTHER PUBLICATIONS

1438 "Effects of High-Energy Protons on Photographic Film", Winter, T. C., Jr. and Brueckner, G. E. 1969, NRL Report No. 6797.

1455 "DOD Solar Experiments in NASA Prototype Space Station", Winter, T. C., Jr. 1970, Military Review, February, p. 58.

1469 "Radiation Light Sources for Stellar Telescope Calibration from 700 Å to 7000 Å", Hunter, W.R. 1969, NRL Progress Report, September, p. 1.

1476 "Spectroscopy in the Space Science Division of the Naval Research Laboratory", Hunter, W. R. and Winter, T. C., Jr. 1969, ONR Reviews.

1500 "Schumann-Type Photographic Film: Preliminary Environment Test Results", Winter, T. C. and Van Hoosier, M. E. 1970, Report of NRL Progress, May.

1504 "Schumann-Type Photographic Film: Preliminary Environment Test Results", Winter, T. C. and Van Hoosier, M. E. 1970, NRL Report No. 7072.

VIII. OTHER TALKS

"The ATM Project", Tousey, R., After-dinner talk at Second International Conference on Vacuum Ultraviolet and X-Ray Spectroscopy of Laboratory and Astrophysical Plasmas, University of Maryland, College Park, Maryland, 25 March 1968.

"Spectroscopy from Space Vehicles", Tousey, R., Delaware Valley Section of the Society for Applied Spectroscopy, Philadelphia College of Textile Science, Philadelphia, Pennsylvania, 15 October 1968.

1442 "Highlights of the Naval Research Laboratory Solar Spectroscopy Program", Winter, T. C., Jr., Department of Aerospace Engineering, University of Connecticut, Storrs, Connecticut, 12 December 1967.

Ibid., Science and Engineering Council, Santa Barbara, California, 1 May 1968.

1436 "Observations of the Sun", Winter, T. C., Jr., Science Institute Thomas Jefferson High School, Alexandria, Virginia, 10 July 1968 and 27 June 1969.
Ibid., George Mason High School, Falls Church, Virginia, 28 October 1968.
Ibid., Washington Lee High School, Arlington, Virginia, 19 December 1968.
Ibid., Swanson Junior High School, Arlington, Virginia, 13 February 1969.
Ibid., Roosevelt High School, Seattle, Washington, 7 March 1969.
Ibid., Gonzaga High School, Science Club at the Naval Research Laboratory, Washington, D. C., 30 April 1969.

1486 "The NRL Solar Observing Program", Scherrer, V. E., Air Force Training Seminar, NRL, 1970-1975 (quarterly).

"NRL Skylab Experiments", Scherrer, V. E., NRL public presentations, 1970-1975 (bi-monthly).

1511 "Apollo Telescope Mount - The First Manned Orbiting Laboratory", Bohlin, J. D. , Hartford County Astronomical Society, Hartford Junior College, Maryland, 17 December 1970.

1568 "Skylab Scientific Acheivements", Schumacher, R. J., Teacher's Seminar, Alvernia College, Reading, Pennsylvania, 17 July 1972.

1659 "NRL's Solar Experiments on Skylab", Schumacher, R. J., Sertoma Club, Lancaster, Pennsylvania, 10 May 1974.

1775 "The Solar Experiments on Skylab", Tousey, R., Boise State College, Orlando, Florida, 13 May 1973.

IX. NON-SCIENTIFIC CREDITS

The New Sun, by Jack Eddy, to be published in NASA Skylab series.

The Amazing Universe, by Herbert Friedman, to be published by National Geographic Society.

National Geographic, "The Sun as Never Seen Before", Vol. 146, No. 4, p. 494, October 1974.

Aviation Week and Space Technology
"Skylab Instrument Reveals New Solar Details", Vol. 99, No. 6, p. 6 August 1973.
"Skylab Enriches Solar Data Hundredfold", Vol. 99, No. 22, p. 16, 26 November 1973.
"The Sun", Vol. 100, No. 2, p. 39, 14 January 1974.
"Skylab ATM Imagery Shows Seething Sun", Vol. 101, No. 13, p. 24, 30 September 1974.

Christian Science Monitor, "Skylab - An Accounting: The Sun", p. F1, 7 February 1974.

Science News
"Peeking Beneath the Sun's Skirts", Vol. 104, No. 7/8, p. 120, 18/25 August 1973.
"The UV Sun Photographed from Skylab", Vol. 106, No. 5, p. 65, 3 August 1974.
"Cosmic Chroma", Vol. 106, No. 8/9, p. 122, 24/31 August 1974.

New Scientist, "The Sun from Skylab", p. 738, 21 March 1974.

Sky and Telescope
"Some Results from Skylab Solar Experiments", Vol. 48, No. 1, July 1974.
"Giant Spicules on the Sun", Vol. 49, No. 4, p. 213, April 1975.

Astronautics and Aeronautics
"Instruments, Systems, and Manned Operations of the Apollo Telescope Mount", p. 50, June 1971.
Cover, May 1974.

Popular Science, "Secrets of the Sun", Vol. 204, No. 5, p. 103, May 1974.

The British Journal of Photography, "Images from Space", cover, 3 May 1974.

Tages Anzeiger, "Die Sonne and wie wenig wir von ihr wissen", Vol. 19, No. 11, p. 34, May 1974.

Electro-Optical Systems Design,
"Optics in the Vacuum Ultraviolet", cover and p. 16, November 1973.
"Vacuum Ultraviolet Detectors and Sources", p. 24, 17 November 1973.

Mainliner, "Solar Power", Vol. 18, No. 12, p. 22, December 1974.

Heating/Piping/Air Conditioning, "Solar Energy in the 1970's", Vol. 47, No. 7, cover and p. 31, July 1975.

Analog/Science Fiction, Science Fact
"Skylab", Vol. LXXXIX, No. 1, p. 99, March 1972.
Ibid., No. 2, p. 95, April 1972.

All Hands, "Lending a Hand in Exploring the Mysteries of Space", cover and p. 33, June 1974.

BBRC 1975 Appointment Calendar, "The Sun We Live By".

NRL Labstracts
No. 35, 4 September 1972

No. 31, 30 July 1973.
No. 33, 13 August 1973.
No. 37, 10 September 1973.
No. 44, 29 October 1973.
No. 49, 3 December 1973.

No. 8, 25 February 1974.
No. 14, 8 April 1974.

(This listing is incomplete, and includes only those publications referring to NRL ATM material that have been brought to our attention.)

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